BY THE SAME AUTHOR,

MECHANICS APPLIED TO THE ARTS.

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# ADVERTISEMENT

TO

# THE THIRD EDITION.

THIS work formed part of a course of Lectures delivered to the Class of Natural Philosophy and Astronomy, at King's College. They have since been revised by the Author, and adapted for publication, in the belief that they may serve the purposes of Popular Instruction. He has to acknowledge his obligations to the following works in the compilation of them: — Lalande's *Astronomy*, Francœur's *Uranographie*, Herschel's *Outlines of Astronomy*, Hymers' *Astronomy*. Some of the more important facts in the recent history of Astronomy have, by the permission of Sir J. Herschel, been collected for this edition from his admirable work.

# CONTENTS.

## DESCRIPTION OF THE PLATE

### IN THE FRONTISPIECE.

THE plate is intended to represent that sphere of the visible heavens on the surface of which the heavenly bodies, —in reality scattered through space at distances from the earth immeasurably *different* from one another,—appear to be placed, at the *same* distance from it. It is on the surface of this imaginary sphere, whose centre is the centre of the earth, that all their apparent motions take place, and it is here that all the phenomena of the heavens must first be studied.

The circular plane which divides the bright from the dark hemisphere in it, is a plane touching the surface of the earth, (shown in the centre of the sphere,) at a point which may be imagined to be in about the latitude of London. This plane is the *horizon* of a person standing at that point. The hemisphere above it is *visible*, and that beneath it *invisible* to him, by reason of the intervention of the earth. Perpendicular to this plane, from the point where it touches the earth, is drawn a line, which intersects the surface of the sphere, in a point marked by a small circle of stars, thus ⁘ which are introduced merely to guide the eye, and instead of letters, and which have no real existence or analogy. This point is the *zenith*. The opposite point of the sphere beneath it is the *nadir*. Obliquely across the interior of the sphere, and passing through the earth's centre, is a line, whose point of intersection with the sphere is marked by two stars, thus . · This line is intended to represent the *axis*, about which the *great* sphere of the heavens appears to turn. It is, in reality, a prolongation to the heavens of the earth's axis.

The two points · . where it intersects the sphere of the heavens, are the *poles* of the heavens. That visible to us in our climate is the *northern* pole, and a star at present near it

is called the polar star. A circle drawn through the poles, and through the zenith of the place whose horizon is shown in the figure, is the meridian of that place. It cuts the horizon in two points, one of which the engraver has marked by four stars, thus ⁚⁚ , and the other by a *comet*. These are the northern and southern points of the horizon. Two points equidistant between these, on the horizon, are its eastern and western points. They are indicated in the engraving each by three stars, thus · · ·

Two circles which traverse the sphere obliquely, and which are shown intersecting one another, in these last mentioned points, represent the *equinoctial*,—a belt of that sphere of the heavens half way between its poles,—and the *ecliptic*, being the circular path which the sun *appears* to travel among the stars in the course of the year. The ecliptic is, in reality, the intersection with the sphere of the heavens of the plane of the earth's orbit in space. In the course of each rotation of the earth, the horizon of any place is made to sweep with its margin the whole surface of the sphere of the heavens, and therefore to pass over every point of it; such a point is then said to *rise* or *set*, as, passing over it, the horizon *discovers* it or *hides* it. In the figure, the horizon has been shown by the engraver to be in the act of passing, among other points, over those two opposite points where the equinoctial and the ecliptic *intersect*, and which he has marked by the three stars. These points are called Aries and Libra, from two signs of the zodiac which commence there. They are also known as the equinoctial points. In every position of the horizon, the equinoctial cuts it in its eastern and western points. When the horizon passes the equinoctial points, it therefore of necessity passes them in its eastern and western points.

The reader will better understand the design of this figure if he imagine the shadow which has been shown projected behind the earth to be removed.

# ASTRONOMY.

## I.

### Are the Fixed Stars greatly more distant from us than the Sun, Moon, and Planets?

The first question which suggests itself to a mind curious to understand the phenomena of the heavens, is probably this —are the sun, moon, planets, and stars really as they seem to be, at equal distances from us, and almost within our reach? or are they, as we are told, some of them infinitely more remote from us than others; and the nearest of them many millions of miles away from us, many thousand times farther than the sun, so far, indeed, that their light, travelling as it does at the rate of 192,000 miles in a second, has, from the nearest, been three or four years in reaching us? And if it be so, how is this known?

Let us suppose an observer to have travelled about, far and wide, on the earth's surface, and accurately to have observed, as he went on, the appearances of the heavens; he will at once have perceived the stars to be bodies scattered about in that great space, whatever it may be, which contains the earth, and he will have remarked that they do not alter their apparent relative positions, as he moves about on it. Their apparent positions, with regard to the *horizon*, are, indeed, continually altering; but with regard to one another, he finds them always the same. This will appear to him very extraordinary, when he considers that the various objects around him on the earth's surface are continually subject to apparent changes of relative position, as he moves about from one place to another. Thus, for instance,—let him be sailing along the sea-coast at night, and let him observe two lights upon projections of the shore. At one instant, when he is

in the line joining the lights, they will appear to him to coincide, blending momentarily into one light; as he proceeds, they will appear to separate, or, in the nautical phrase, they will *open*; and this opening of the lights will continue, until they have at length acquired a certain maximum apparent distance. They will then appear to approach one another; and as he finally leaves them behind him, they will go through all the same circumstances of apparent displacement as attended his approach to them. If the lights be sufficiently remote, all these changes in their apparent distance from one another will be referred to, and apparently take place upon, the circular margin of the horizon. They will seem like two "beads of light" moving towards one another on the *circumference* of that circle; coinciding, then receding, and again approximating to one another. These apparent motions are called parallactic.

Analogous changes of *bearing* may be observed in objects situated at different distances from us, in the daytime.

Now, why are there not changes of apparent relative position like these among the stars?

A slight consideration will show our observer *that this can only be accounted for by supposing the distance of the stars to be exceedingly great, as compared with any distance through which he can himself move.* He can prove demonstratively that the parallactic motion arising from any given change in his point of view, is necessarily less as his distance is greater; and that when that distance is extremely *great* in comparison, and *then* only, the parallactic change in the position of the object is insensible.

Let a man look through his window at any two stationary objects without,—two chimneys for instance; if these be at no great distance from him, he will perceive, that by changing his position ever so slightly, their apparent angular distances from one another will be changed, and he may, indeed, readily so far change it as to cause one to appear behind the other. Let him now look at two other objects more remote than these, he will find that the same motion of his point of

view will not produce the same variation in *their* relative positions: and if the objects be *very* distant, the variation which he can thus produce will be imperceptible. Were he, however, to use an *instrument*, such as are every day constructed for measuring the angular distances of distant objects, there are scarcely any two within the reach of his vision, which would not appear under different angles, when viewed from different parts of his room.

It is upon this principle, as has been observed by Sir J. Herschel, "that in Alpine regions, visited for the first time, we are surprised and confounded at the little progress we appear to make by a considerable change of place. An hour's walk, for instance, produces but small apparent change in the relative situations of the vast and distant masses by which we are surrounded. Whether we walk round a circle of a hundred yards in diameter, or merely turn ourselves round upon its centre, the distant panorama presents almost exactly the same aspect—we hardly seem to have changed our point of view."

On the whole, then, since, when we pass from one point on the earth's surface to that which is even the most remote from it, we perceive no change in the apparent relative positions of the stars of that kind which has been called parallactic; it follows, with the most certain evidence, that these stars are immensely distant from us.

But a still more accurate notion of the effect of parallactic change may be obtained as follows:* let a circle be measured only a few yards in diameter, and an observer walk round it, measuring, with an instrument contrived for that purpose, the angular distances of two objects, only just visible on the edge of the horizon: he will obtain in every different position, a different measurement; and instruments have been made of such nicety, that different positions on such a circle would give differences in the angles observed, even when the distances of the objects were at least 100,000

* See HERSCHEL's *Astronomy*, page 51.

times the diameter of the circle. Now instruments of this kind, and of the most perfect workmanship, have been employed to observe the angular distances of the stars from points differently situated on a great circle of the earth, and no parallax has ever been traced.* It follows, therefore, *demonstrably*, that the distance of the stars is more than 100,000 times the diameter of the earth. Now the earth's greater diameter is 7925 miles. Imagine, then, these 7925 miles taken 100,000 times, and a great sphere described, having that line for its diameter, and the earth for its centre; we are certain that the region of the fixed stars is without that sphere.

Although the fixed stars are thus observed to have no parallactic motion, yet the sun, the moon, and the planets have. These we may conclude then, with equal certainty, to lie within that imaginary sphere of which we have spoken; and their distance from us to be less than 7925 miles taken 50,000 times.

## II.

### The Appearances of the Heavens.

Whoever watches the stars throughout the night will find them to have a motion around him, rising from under the horizon to the East, and setting beneath it in the West; and the time occupied in this revolution to be nearly equal to that between sunrise and sunset. As these stars thus advance across the heavens, their places he will observe to be continually supplied by others, emerging, as it were, from some space beneath the horizon. These stars he will perceive not to move freely and independently of one an-

* Although no parallax has ever been discovered in the stars by looking at them from different points of the earth's surface, yet there has been such a parallax found, of late years, in certain stars, when seen from different points in the earth's orbit. From the parallax thus discovered by Bessel in the star 61 Cygni, it appears that star is distant from us 657,000 times farther than the sun.

other, but to partake in a *common* motion of the great canopy of the sky, round a certain point called its pole, whose position is due North of him, and whose height from the horizon may, in our latitude, be found by dividing the whole distance from the horizon to the zenith (that is, to the point immediately above our heads,) into ninety parts, and taking about fifty-one of them. All the stars will appear to describe as it were bands of the sky, equidistant from that pole. Or the phenomenon may, perhaps, be better described by supposing the whole concavity of the heavens to turn round a line, drawn from him to that point, as a globe turns upon its axis.

He will soon, moreover, be convinced that this revolution is continued not only during the night, when he *sees* it, but during the day, when he does not; for, at the beginning of the next night, he will find the very same stars, which on the preceding morning had disappeared, descending *westward*, now rising again *eastward*, having revolved during the day through some region unknown to him, and apparently beneath his feet, from the margin of the western to that of the eastern horizon.

He will, moreover, perceive that there are certain of the stars which disappear from him in the light of the sun at daybreak, which, nevertheless, can never go below the horizon; those, for instance, which lie immediately in the neighbourhood of the point called the pole, about which the whole turns. This point lying a considerable distance above the horizon, those stars, such as the constellation called Charles's Wain, or the Greater Bear, which are near it, and consequently describe small circles round it, can never pass beneath the horizon. The disappearance of these stars in the daytime, he will readily attribute to the greater brightness of the daylight, as he perceives artificial lights to be rendered scarcely visible in sunshine, and some of the smaller of the same stars to be invisible in the moonlight.

As of that half of the great sphere of the heavens which is above him, he perceives that there is a certain portion

which, by its rotation, is never made to sink below the horizon; so of that half which is below him, he will conclude that there must be a certain portion which never rises above the horizon.

> Hic vertex nobis semper sublimis at illum
> Sub pedibus Styx atra videt manesque profundi.

It will thus seem to him that he stands in the centre of a great hollow sphere, on whose surface the stars are sprinkled. That this sphere moves continually round an axis, whose direction is inclined from him upwards to the pole; but that he can only see one half of it, or a hemisphere, as it is called, at once.

Impressed with this notion, let us suppose him to move from the position in which he first stood continually in any given direction, as, for instance, westward. He will find that in each new position in which he places himself, he still seems to be in the centre of a sphere of the heavens, in which similar stars appear, and which apparently revolves like the first, and round the same axis.* But the same sphere cannot have two centres. If then in his first position, he was really in the centre of a sphere of the heavens, it follows that in his second position, he is as certainly in the centre of a second sphere, and that there are as many spheres of the heavens as he can take up positions; containing all of them the same stars, and revolving all round axes similarly situated, and in the same direction, without interfering with one another. This is manifestly absurd, and he is soon forced on to the conclusion, that go where he will, he is still looking upon the same heavens and the same stars. And that in the appearance of a sphere, of which he seems to form the centre, there is some deception of the senses.

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* That is, an axis going through the same point in the heavens—the same star, for instance, if one existed there—as before. The axis may be apparently inclined in a position different from its first position, but will still intersect the heavens precisely as before.

This view of the case his experience corroborates; he finds that he judges of the distances of remote objects from one another, by the number and variety of other objects, which lie within the range of sight between them,—the mind proceeding in the process as it were step by step, so that if there be no such other objects intervening between those which he observes, or if he can see none, he can form no idea of their relative distances. On a dark night, for instance, two lights, one of which is greatly further from him than the other, will appear at the *same* distance, since none of the intervening objects are visible to him. And for the same reason, the common distance at which they *appear* will be greatly different from the real distance of either of them. The stars, then, although they appear to him all at the same distance, may, in point of fact, be all of them at very different distances, and scattered anywhere through the realms of space.

He will arrive at a similar conclusion from the appearance of the clouds. A little experience and observation will convince him that these are, in point of fact, huge masses of vapour floating at rest in the air, or swept over the earth's surface, in long irregular lines, by the winds. Yet these appear to him to form part of the concave of the heavens; all their parts are pretty nearly at the same apparent distance from him; and a long stream of them in motion to any point of the compass, instead of moving in a right line, appears to wind round him in the segment of a circle.

Thus he clearly perceives himself to labour under an optical deception, by which all the objects situated beyond a certain distance, are made to appear to him to form part of the surface of a sphere of which he is the centre. And it follows that the stars may be fixed in any way, however irregularly in space, and however far off, and yet that, go where he will, they may always appear to him to lie upon the surface of a spherical vault like that of the heavens.

## III.

### The Figure of the Earth.

Now, let us suppose our observer to continue his journey in that western course on which he first set out. Journeying on continually, he will find himself at last, to his great astonishment no doubt, in the very position from which he started. And in whatever direction he began his journey, provided he continue to move accurately in that direction, he will find himself eventually to return to the same spot.

Now from this it is abundantly evident that the earth cannot be a continued *plane* or flat surface, for, if this were the case, the further he moved in the same direction, the further he would certainly always be from the point from which he started. It must, in fact, be a surface without limit or termination, and returning into itself, like that of a solid body; such a surface being the only one from any point in which any line drawn always in the same direction will eventually return to that point again.

But perhaps it will be opposed to this argument, that the journey supposed to have been taken has never, in point of fact, been made — that no one has ever set out from any place on the earth's surface, advanced with his face always in the same direction, until he returned to that place. This is very true. But suppose the case of a number of different individuals respectively performing different portions of this journey, and all registering and comparing their observations, and the case will be brought very nearly, if not entirely, within the limit of that which has actually been effected.

Look at the matter, however, in another light, and the nautical experience of every day presents us with a conclusive experiment. Suppose a vessel to set out from the port

of London, and to sail so that her course shall always be either due west, or due north, or south, or between these points; or, in other words, let her course never be in any degree towards the eastern point of the compass. Now it is clear that if the earth were a plane surface, or a surface of any kind which extended indefinitely, so as not to return into itself (enveloping a space within it), a ship sailing thus could never return to its port again. She might wander on and on to eternity; but until she put about, and took an eastward course, her voyage could never terminate in the haven whence she began it. Now this is what is done continually. Vessels are said to sail every six weeks, from the port of Liverpool, on a south-western course to the latitude of Cape Horn; they then take a north-westerly course to Van Diemen's Land or New Holland; from thence they continue their voyage still in a north-westerly direction, probably to some of the islands of the Indian Archipelago, or to Bengal; and thence *again* sailing westward, but towards the *south*, they double the Cape of Good Hope, and, coming round northward, they find themselves approaching the region from which they set out; and at length make the very port from which they first sailed.

Here is a voyage, then, made continually towards the west, bringing the traveller again to his home; a line drawn continually towards the same *parts* returning into itself. Now such a line can only be drawn upon a *surface* which returns into itself, and encloses, or would enclose, a solid. This voyage would be utterly impossible, as every one may see in a moment, if the earth were a plane or any continued unlimited surface. Were this the case, travelling on continually westward, you would wander on for ever. Now voyages and journeys of this kind, have been made in every conceivable direction over the earth's surface, and always with the same result. It follows, therefore, that the earth's surface, in every direction, returns into itself; nowhere extending to infinity. It is not, for instance, a cylinder of an infinite

length, but finite diameter, which we may gird *round* its surface, but not in the direction of its length. We do not live about the vortex of a paraboloid or hyperboloid, or about the summit of a cone, whose inferior surface spreads out to infinity, and whose base reposes in the abysses of space. The surface of the earth is finite in every direction, and the mass which it encloses is one wholly separate and detached from every other.

Now observe the importance of the fact which we have thus arrived at. Since the earth is a mass, thus separate and detached from any other, *it reposes or rests upon no other*, as we perceive bodies here to rest upon one another. We have great difficulty in conceiving this fact, which is nevertheless demonstratively proved: it appears to us utterly impossible, and opposed to daily experience, that anything should repose, and yet be *unsupported*, without any foot or pedestal, or plane to rest upon. All this is easily explained, but it does not belong to this part of our subject to explain it. The reader must for the present content himself with the broad fact, which has been absolutely and completely proved to him, that the earth is a finite mass, bounded everywhere by a surface which returns into itself; nowhere reposing or resting upon any other mass, but, by some means or other, poised in mid space, by an indwelling energy or power, or some unseen influence from without. It is a solid mass,—a lump of matter; or it is a hollow mass, having a surface like a solid.

The argument on which this conclusion is founded is *perfect;* it is an absolute demonstration.

There is a common illustration of the fact that the earth is not, as it seems to be, a *flat* surface, but that it is curved, drawn from the manner in which a vessel first becomes visible, as it approaches the shore from a distant voyage, or disappears as it leaves it; it is very valuable, inasmuch as any one may repeat the observation for himself, by going only as far as the sea-coast.


If the surface of the earth be curved, as represented in the figure, and the eye of an observer be placed at S, it is clear that to see any object placed elsewhere on it, as at C, D, or E, he must look through the mass of the earth in the directions of lines drawn from S to these points. Objects situated at C and D and E would therefore be invisible to a spectator at S; and, in fact, all objects situated beneath a line, S B, drawn from S, touching the surface of the mass in the point S; whilst all objects above that line would be visible to him. Thus, a high-masted ship approaching him, in the direction E D C A, or leaving him in the direction A C D E, would, as long as the whole of it lay beneath this line, S B, be invisible; and the first part of it which found its way above this line, or the last part which remained above it, being the topmast, would be the first to appear, or the last to disappear; and thus, as it approached, the different parts of the ship would, in order, rise into sight, until the whole of it, appearing above the line S B, would become visible; or, if it was leaving him, sinking more and more beneath that line, as it receded, the whole would become gradually invisible.

Now this is precisely what any person who made the observation would find to be the case, wherever he made it on the earth's surface.

The appearance represented in the next cut, is that which a ship always offers as it goes out of sight on a distant voyage.

He would also perceive that, if the earth were a perfect plane, or flat, not the topmast, but the stern, must, of necessity, be the last part visible. Here again, then, he positively concludes that the surface of the earth is a curved surface.

There is yet another proof of the curved form of the earth, which, like the first given, is a complete and absolute demonstration of its continued surface and finite dimensions; and which, although in introducing it, a fact will be *twice demonstrated* (which is contrary to the rules of sound reasoning), it is yet desirable to give, because the reader will be led on by it yet another step in investigating what is the real and accurate form of the earth's surface, and in determining what are its *dimensions*, as well as its form.

If an observer set out from any northern latitude, and travel southward, he will observe the *altitudes* of the stars to the north of him, or their heights above the horizon, continually to diminish. They will appear to sink behind him as he advances, and, in point of fact, he will eventually lose them, one by one, to the northward, and see other stars rise, one by one, upon the vault of the heavens, to the southward. This is an observation made every night, by thousands of persons in vessels sailing from Europe to the southern hemisphere. That star which we call the Polar Star, because the whole concave of the heavens appears to us to turn round it, and which, with us, is seen at a height above the horizon, considerably more than half of the whole height of the heavens, appears to them continually to descend, until, at length, when they reach the equator, it buries itself in the ocean, and becomes, as they pass to the southern regions of the earth, invisible to them. That bright and well-known constellation, called the Greater Bear, which lies near the Polar Star, and, in completing its revolution about it, never, with us, sinks beneath the horizon,* appears to them, first of all, only just to dip itself into the ocean once every twenty-

* "Arctos metuentes æquore tingi."—*Georg.* i. 246.

four hours, then to bathe itself deeper and deeper every day, at length to remain immersed for twelve hours every day, and finally to disappear under the waters.

Now this continual descent of the star to his horizon, and beneath it, as the observer moves along the earth's surface, must result either exclusively from *his* motion, the star and horizon being at rest, or from his motion combined with that of one or both of the other two. The star and horizon must both remain at rest, and the *observer only move;* the approach of the star to the horizon being an optical deception, resulting from this cause; or, as he moves, the star and horizon must, at the same time, one or both approach one another.

Now the first supposition, that the phenomenon results from his own motion exclusively, and not from any motion either in the horizon or the star, is manifestly inadmissible. If his horizon do not alter its position, then the surface of the earth, to which it is a tangent plane, must be a *plane* surface; and the simple motion of the observer on the earth's plane surface must be sufficient to account for the apparent sinking of the stars behind him. Now this is impossible, as may readily be shown.* The star must then approach to

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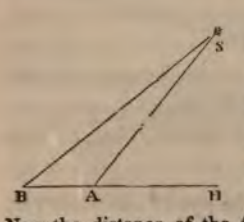
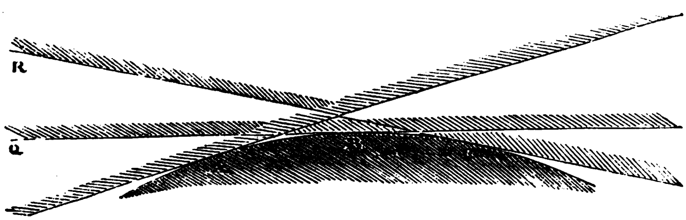



* Let S be a star seen by an observer at A, whose meridian is B A H. The angle S A H will then be the apparent elevation of the star above his horizon. Suppose him to move to B, the elevation of the star will then be S B H, and the difference of these elevations, that is, the apparent sinking of the star will, by Euclid, be the angle A S B. Now the distance of the fixed stars has been shown to be infinitely great, as compared with any distance measured on the earth's surface. S A is, therefore, infinitely great, compared with B A, and therefore the angle S B A is infinitely great, compared with A S B; that is, A S B is infinitely small, or the *sinking* of the star, is on the hypothesis, infinitely small, and would not be perceptible: but it *is* perceptible. The hypothesis is, therefore, false, or the horizon and star do not both rest as the

the horizon, or the horizon to the star, or each must approach the other. But the former of these suppositions is evidently absurd: no man can conceive that a star should actually move its place whenever he moves, and keep its position only when he stands still. The star does *not* then *move* to the horizon; and it follows, as the remaining alternative, that the horizon moves to the star. His horizon, then, alters its position as the observer moves, revolving continually *towards* those stars which are behind him, and *from* those which are before him.

Now we have before shown that the horizon of an observer, anywhere on the earth's surface, is a plane drawn through his eye, touching the earth,—it is a tangent plane to the earth's surface; and we have now shown that this plane alters continually its direction; its position is different for different points of the earth's surface. Here then is a complete geometrical proof of the curvature of the earth; for that surface which has, at different points, tangent planes in different positions, that is, which, when produced, do not coincide with one another, must be a curved surface. And on this supposition, the phenomenon is readily explained.



Let A B C be different positions of the eye of our observer, and we may suppose his eye to be actually within the earth's surface, since his height is comparatively very small. Then

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observer moves. There remain, then, only the hypotheses that the horizon approaches the star, or the star the horizon, or that each of them approaches the other as the observer moves.

will the planes C R, B Q, A P, which must be imagined to be infinitely extended, be the horizons of the observer, or planes beneath which nothing will be seen by him in these several positions. It is apparent that, as he passes from A to C, his horizon, as it were, *rolls* with him; and by this motion, the distance between it and any star measured on that imaginary vault of the heavens to which he refers the position of the star, is continually made to diminish; also, not being conscious of the motion of his horizon, he attributes the motion to the star, which he imagines to sink continually behind him as he moves onwards.

But there may be an infinity of curved forms. The question then arises, what is that particular form of curved surface which bounds the mass of the earth? What is the *shape* of that lump of matter of which we have ascertained it to be composed? Is it a cylinder or a cone, of an oblong or an oval form, or is it an irregularly shaped mass? We can now answer this question satisfactorily. It has been shown that, as an observer moves about on the earth's surface, the horizon, as it were, *rolls* under his feet from place to place.

Now, if this rolling motion of his horizon be uniform, so that, whilst he moves over the same distance *anywhere* on the earth's surface, and his horizon is thus made to roll over the same distance, it also is made to describe the same *angle* towards the stars; it is clear that the earth's surface must have everywhere the same curvature, and be a sphere; for if it have anywhere a greater curvature than elsewhere, it will then necessarily roll through a greater angle, in rolling *over* the *same* space. Thus, for instance, if we make a plane flat surface roll over *an inch* at the sharper or more curved extremity of an egg, it will evidently roll through a greater angle than when made to roll over *an inch* at the thicker extremity, or on either sides of the egg. Now, the *angular* motion of the horizon of an observer, travelling over the earth's surface, may be ascertained by its angular approach to any fixed star; and it is found, by numerous actual observa-

tions of this kind, that when the horizon of an observer is made, in any two different places on the earth's surface, by a change of the same distance in his position, to roll over the same space (say sixty-nine miles), due north or south; it revolves also through *very nearly* the same angle, approaching or receding from any fixed star by the same angular quantity. It follows, then, with absolute certainty, that the earth is very nearly a sphere. Very nearly, because the angle through which the horizon thus rolls, in any two different places, is not *exactly* the same; it is slightly greater towards the equator than at the poles. The earth is, therefore, slightly more curved at the equator than at the poles. Its form, in fact, is somewhat that of an orange; the polar regions corresponding to the parts about the extremities of the shorter diameter of the orange.

## IV.

### The Dimensions of the Earth.

There is no manifestation of wisdom in creation more remarkable, perhaps, than this,—that a being so infinitely minute in the comparison as man is, should be rendered able to ascertain the form and dimensions of the huge mass on which he dwells, and of other worlds than this, of equal or greater magnitude, situated at distances in the space around him so great, that, large as they are, they are scarcely visible to him by reason of their remoteness. Let there be conceived an insect less than the least ever seen with the naked eye, one of the animalcules* to be traced by the aid of powerful microscopes in water, and let such a being be placed on a globe, a foot in diameter. Conceive this little being, not moving

* To realize the proportion, an animalcule must be conceived so small that between three and four millions might be drawn up in a file, and stand side by side in the space of an inch.

above the one-tenth of an inch over its surface, by the aid of an instrument, a hundred times less than himself, to make certain observations on the objects which surround this globe; and let this mite be endued with an intellect which enables him, from these observations, (linking argument and argument, and piling conclusion upon conclusion,) to say, positively, from that tenth of an inch of the globe, and that little instrument, what are the dimensions of the whole globe,—what is its circumference, and its surface, and its diameter, and its weight; and knowing these, to conclude from thence the weights, dimensions, and distances of all the other objects bearing any proportion to the magnitude of this globe, within forty or fifty miles round it; nay, to carry his speculations to certain conditions of the existence of objects whose distances from him must be measured by thousands of miles. Let all this be conceived, and then let this globe be converted, in the imagination, into the mass of the earth, and the space round it into the heavens, and some conception will thus be obtained of the position which the astronomer holds in the universe.

Let us suppose our observer to have by this time acquired sufficient knowledge of geometry, to perceive that the angle through which his horizon revolves between any two stations is, in point of fact, the same as the angle made between two lines drawn from those two stations to the earth's centre;* and very little knowledge of geometry is necessary for this purpose. Thus it follows (and this is a very remarkable fact,) that as he thus moves from one place to another, his horizon rolls through precisely the same angle which, if we imagine a line drawn continually from the earth's centre to his feet, that line would revolve through between the two places.

Thus, referring to the diagram in the note at the foot

* Thus let A and B be two positions of the observer, and let AC and BC be perpendiculars to the horizon at those points, which, if the earth

of this page, as our observer moves from A to B, a line imagined to be drawn continually from the earth's centre C, to his feet, will revolve through the angle A C B. Now the angle A B C is precisely equal to the angle through which his horizon has, during the same time, been made to revolve. If, then, we know, or can find out one of these angles, we know, or can find out the other.

If we know the angle through which the horizon has revolved, we know the angle through which the line drawn to the centre has revolved; and conversely. Now, the angle through which our horizon has revolved, when we have moved from one place to another, we can always tell by observation. We have only to observe by how great an angle any fixed star has apparently been made to approach the horizon or recede from it. For what appears to us to be the approach of the star to the horizon, is in reality nothing more than the approach of the horizon to the star; and what appears to be the elevation of the star above the horizon, is the sinking of the horizon below the star. Thus, then, we have only to observe the angle through which (by reason of our motion)

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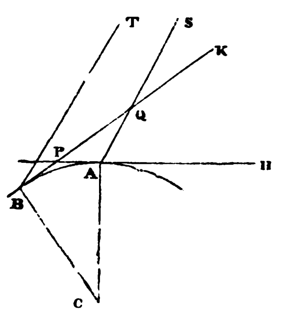



were accurately a sphere, would meet in its centre. Let S A and T B be straight lines, drawn from a star to an observer, at the points A and B; these lines are parallel, since the star is infinitely distant. Let A H and B K be the horizons at A and B; then are S A H and T B K the altitudes of the star, as seen from A and B; and the descent, or sinking of the star, by reason of the motion of the observer from A to B, is the difference of these altitudes. Now, since A S and B T are parallel, therefore T B K is equal to B Q A, and the difference of B Q A and S A H is Q P A; therefore the difference of T B K and S A H is Q P A. Q P A is therefore the difference of the altitudes of the star at the two points of observation.—Now Q P A = A C B; ∴ &c.

the star appears to sink or to rise; and we shall know the angle through which our horizon has really been made to revolve; and, therefore, the angle through which an imaginary line joining continually the place on which we stand, and the centre of the earth has been made to revolve. If, for instance, a star has apparently ascended or descended one degree by reason of our change of position, it is our horizon which has in reality revolved through that degree; and, therefore, the line drawn from our feet to the centre of the earth has, by our motion, been made to revolve through one degree, or the 360th part of a complete revolution. We have therefore manifestly, when we have done this, moved over the 360th part of a whole circumference of the earth. And if the actual *distance* through which we have moved be measured, we shall know what distance is one 360th part of the whole circumference of the earth. It will be found to be very nearly sixty-nine miles and one-tenth, or accurately, 69·08 miles. 69·08 miles, then, is the 360th part of the circumference of the earth, or 69·08 miles taken 360 times is the circumference of the earth. It will thus be found to be 24,869 miles.

Knowing thus the circumference of the earth to be 24,896 miles, the rules of geometry tell us that its diameter must be 7916 miles.

Thus, then, it has been accurately demonstrated; and, if the reader has followed the argument, he *knows* with as certain a conviction as that which may be obtained from a proposition of Euclid, that this earth on which we stand is a great ball, somewhere about 25,000 miles in girt, and 8000 miles in diameter; so that vertically downwards, 4000 miles beneath us, is its centre, to which we might complete a journey, travelling day and night, at the rate of ten miles an hour, in about sixteen days.

We have great dicffiulty in forming any conception of so huge a mass. The largest object we have an opportunity of observing, and obtaining the same notion of as we

usually do of the dimensions of objects, is a mountain. Now, the greatest elevation on the earth's surface is not more than five miles in height. If it were, instead of five miles, 250 miles in height, it might bear the same relation to a sector of the mass of the earth, that an object lying in the space beneath the dotted line in the accompanying diagram might do to the whole figure. Being, as it is, only five miles, or one-fiftieth of this in height, it is impossible to make a mark on the figure such as could be seen, which would at the same time represent the proportion of the greatest mountain in existence, to one narrow slice or sector of the mass of the earth. The ocean, it is probable, nowhere exceeds five miles in depth; the extreme inequalities of the solid portion of the earth's surface are, therefore, nowhere more than ten miles. This is one-twenty-fifth of the space included between the curved lines in the diagram, a distance which will about be represented by the thickness of the paper on which this is printed.

Thus, then, any irregularities which exist on the surface of the earth are as nothing when compared with the whole mass of it. The greatest mountain is but as a speck of dust on the surface of this globe; the deepest sea but as the irregular and almost imperceptible erosion of its surface, which, if it were of metal, might be produced by the action of the air upon it; and the channel of a mighty river but the scratch which might be made upon it by the slightest pressure of the point of a needle. If this huge mass be, as in-

deed we know it to be, subjected to the action of central heat, how slight a development of this would be required to obliterate a continent or upheave the rugged bottom of an ocean. The merest throb, the most imperceptible breathing of the huge mass, the feeblest pulse of its great heart, would be sufficient to account for a complete change in the relative positions of land and water. Such changes we know, at different times, to have taken place: there is scarcely a single spot on the earth's surface, now dry land, where, if you seek for them, you will not find evidences that it was once at the bottom of an ocean. And considering that the earth, so far as we can examine it, is composed of substances of an infinite variety of different kinds, as to their chemical constitution, and which are subjected, more or less, to the operation of heat, and possibly of intense heat, it is so far from being a wonder that the thin film of hill and dale, land and water, which constitute its surface, should alter its form by reason of the internal action of its component parts, that it seems to be something little short of a miracle which preserves it from day to day at all in the same form, and which restrains the tendency of its materials to rush into one universal conflagration.

Of the internal composition of this huge mass we know little or nothing *certainly:* it is an attractive field, therefore, for speculation, and one by no means neglected; the labourers in it are very numerous. To account for volcanoes, which are but as here and there, and at long intervals of time, the weepings of some pore of the great body of the earth; some of these demand that we should conceive what we stand upon to be but a shell, wherein is enclosed a vast lake of burning matter: this huge caldron, on the scum of which we must be supposed to be dwelling, they take to have its contents perpetually in a state of circulation; and sometimes, by some storm upon the surface, to upheave the crust which covers it in an earthquake; and at others, through some abraded portion, or some crack in it to let out a volcano. Others, again,

tell us that, about the earth's centre, there dwell, in their primeval metallic lustre and purity, unsullied by all touch or tarnish of oxygen, the metallic bases of the alkalies and earths,—the hidden spirits and active principles of which the solid material substances on which we tread are but a gross oxygenated manifestation; that, ever and anon, water breaks in upon this sensitive mass, and then follows that train of epidermatous calamities which we know the earth occasionally to suffer under; for these metals are some of them so exceedingly impatient of the presence of water, that they become convulsed at the approach of it, and its actual contact causes them to burst into a flame: so that, in point of fact, volcanoes are no more than the developments of that impatience of the presence of water, that hydrophobia which possesses the fluid metals occupying the interior of the solid film or shell on which we live.

Such being the *hypotheses* which have been made with regard to the mass of the earth, its interior construction and substratum, the reader need scarcely again be informed that the subject is one on which very little is really known. That little is comprised in our astronomical and geographical knowledge of it, and in that system of geological facts (as distinguished from geological speculations) which has been, of late years, so rapidly accumulating.

It may, perhaps, here be mentioned, as connected with this subject, that the mean density of the earth is ascertained to be about $5\frac{1}{2}$ times that of water, and that this is greatly less than it would be if the masses near the centre, subjected as they are to enormous superincumbent pressures, yielded to those pressures according to the same law that we find them here to yield.

Further, it may be mentioned, that the variation of temperature, at different depths beneath the earth's surface, is ascertained to be an increase of somewhere about 1° of Fahrenheit for every thirty-seven English feet: now, if this law of variation do really *continue* as we descend, it is ascertained

that the temperature of boiling water will be acquired at about two miles below the surface, and that of melting iron at about twenty-four miles. At the centre it might be somewhere about 120 times this heat.

The question, however, after all, of the internal structure of the earth, is one which scarcely belongs to astronomy; sufficient is not known of it, indeed, to claim for it a place in any science. The dimensions of the earth and mean density are all that the astronomer troubles himself about; its dimensions, when known, serve him as a scale whereby to measure the distances and dimensions of the other planets of our system, and its density enables him to *weigh* them. The determination of the positions of places on the earth's surface, and the tracing of the boundaries of land and ocean, constitute the science of geodesy.

## V.

### The Poles of the Earth.—Its Equator.—Latitude and Longitude.

As will be shown hereafter, the earth turns perpetually round one of its diameters, producing thereby the alternations of day and night; this diameter is called the *axis* of the earth, and its extremities are the *poles*. A circle drawn midway between the two poles is called the *equator*, and the two equal portions into which this equator divides the earth, are called its northern and southern hemispheres. A great circle * anywhere drawn round the earth, through its two poles, is called a meridian, and being drawn through any particular place, it is called the meridian of that place. The

* A circle may be described on a sphere as *small* as we like, but we cannot describe a circle as *large* as we like. The largest circle which we can describe is called a great circle. It is that whose plane goes through the centre of the sphere; or, if we cut the sphere through its centre, it is that circle which would bound the section. We can, manifestly, describe as many as we like of circles as great as this on the sphere, but none greater.

whole meridian being supposed to be divided into 360 equal parts, each of these is a degree, and the number of these degrees between the equator and any place through which that meridian passes, is called the latitude of that place. Each meridian going round the earth passes through the equator, and cuts it at right angles. This equator being divided like the meridian into 360 parts or degrees, the number of these degrees between the meridian of any place and the meridian which passes through the observatory of Greenwich, is called the longitude of that place. It is called east or west longitude, according as the degrees are counted eastward or westward from the meridian of Greenwich.

Knowing the latitude and longitude of any place on the earth's surface, we can find out the spot corresponding to it on an artificial globe or on a map; for counting off a number of degrees equal to its longitude on the equator east or west of the meridian of Greenwich, we learn the position of its meridian; and counting off on this meridian a number of degrees from the equator equal to its latitude, we find out whereabout the place is on its meridian. Thus knowing its meridian, and knowing whereabout it is on it, we know the exact position of the place.

Thus, if P be the north pole, and Q the south, a circle E R midway between them is the equator, E P R is the northern, and E Q R the southern hemisphere. Also, if A be any place on the earth's surface, then a circle P A Q, going through P, A and Q, is the meridian of A. If the whole circle of this meridian be divided into 360 equal parts, each of them is a degree of latitude, and the number of these degrees between A and B, where the meridian of A cuts the equator, is the latitude of A; whilst if P M Q be the meridian passing through Greenwich, and the equator E R be similarly divided into 360 degrees, each of them is a degree of longitude, and the number intercepted between B and M is the longitude of A.

On the ocean there are none of those means of ascertaining the exact position of any place where we may be, that are to be found on shore; there are no known objects that we can recognise, there are no beaten tracks with the direction of which we are acquainted, and there is no one of whom we can inquire. But could we ascertain by any means the latitude and longitude of the place we are in at any time, we might easily find out, by reference to the globe or the map, what that place was, and in what direction, or at what distance it lay from the place of our destination; thus we should know how to shape our course, and be able to tell when our voyage would probably end.

The determination of the longitude and latitude by astronomical observation is, therefore, the great problem of nautical astronomy, and with such accuracy is this problem now solved, that ships are frequently months at sea without sight of land, and yet is their course steered continually, and almost without wandering, to some little speck of land, of which they see nothing until they are within a mile or two of it, but towards which, for thousands of miles, their voyage has been directed through the pathless wilderness of waters.

The following is a method of determining the latitude: we shall point out several others as we proceed.

## VI.

### To determine the Latitude of a Place on the Earth's Surface.

Suppose an observer to be situated at the equator of the earth; his horizon touching its surface will then be parallel to the earth's axis, and the polar star will just be apparent upon its margin. Let him now move northward; for every degree of the circumference of the earth over which he thus moves, the star will appear to ascend one degree, his horizon rolling from the star one degree. Thus, then, if he travel on the meridian, the ascent of the star in degrees, or its height above the horizon from which it has ascended, will always equal the number of degrees of the meridian over which he has travelled; but this number of degrees is the latitude. His latitude is, therefore, always equal to the elevation of the polar star above his horizon. Here, then, we have a very simple and easy method of finding the latitude. We have only to observe with an instrument, constructed for that purpose, the number of degrees in the elevation of the polar star above our horizon, and this will always be the latitude of the place where we make our observation. We have here supposed the polar *star* to be accurately in the pole of the heavens, which it is not. It will hereafter be shown how any inaccuracy arising from this cause may be got rid of.

In speaking of the ascent or descent of a star caused by a change in our position on the earth's surface, we have supposed the heavens to be apparently at rest, so that any alteration in the apparent position of the star, must result from our motion, and nothing else. Now, in point of fact, every portion of the heavens except its pole, and every star in it,

except the polar star,* appears to be incessantly in motion, so that even if we did not move *our* position, *they* would still apparently move, revolving completely round in twenty-four hours.

In ascertaining the variation of latitude by observation upon the apparent motion of a star, it becomes, therefore, necessary to allow only for that motion which arises from the observer's change of place, and reject that which arises from the apparent diurnal motion of the heavens. If, for instance, making an observation on the height of a star here at six in the evening, I travel sixty-nine miles, or one degree northward, and make another observation upon the same star; except I make this observation precisely at the expiration of a particular time from my first observation, I shall find that the star has altered its position much more than one degree; it will have revolved with the heavens through a considerable space, and this cause, much more than my motion, will have tended to alter its apparent position. This difficulty may be obviated by the following considerations.

Let the plane of the meridian of the observer be supposed to be produced so as to intersect the great vault of the heavens, its intersection will cut out a great *circle* of the heavens, called a celestial meridian. This circle passes through the pole of the heavens and the zenith† of the observer; and since the altitude of a star is measured directly from the horizon to the zenith, when the star is on the celestial meridian its altitude is measured on this circle. Now, let us suppose the altitude of a star to be thus measured when it is on the celestial meridian, and let the observer travel to some other place southward, the star will in the

* The polar star is not accurately at the pole; it turns, therefore, apparently round it, but it is in a very small circle that it revolves, so that it may be considered *nearly* at rest.

† The zenith of an observer is the point *immediately above his head* in the heavens.

mean time move off the meridian; and if he observe it again when it is so off the meridian, he will not know what part of the motion, which he will observe to have taken place in it, is due to his change of position, and what is due to the motion of the heavens. But let him wait until the star comes on the meridian again, (which it will do after twenty-four sidereal hours, or after $23^h\ 56'\ 44{\cdot}09''$ mean solar time,) and then make his observation, and the result will be precisely the same as though the star had not moved at all during the interval, for it will have returned to precisely the same place on the meridian as it had before. He may therefore suppose it not to have moved. Thus, then, observing the *meridian* altitudes of a star at two different places, the difference of *these*, (that is, the angular ascent or descent of the star,) he knows to equal the difference of latitudes of the places of observation.

## VII.

### The Spheroidal Form of the Earth.

A sphere has this property, that all lines drawn from its centre, so as to make equal angles with one another, include equal distances or lengths on its surface between them. Hence, therefore, if the earth be a sphere, any two lines drawn anywhere from its centre to its surface, so as to include the same given angle, say one degree between them, will include also the same length on its surface between them; or the length or distance between these points, measured on the earth's surface, will be the same wherever the two points are taken. The question, whether the earth be a sphere or not, is therefore readily put to the test.

We have only to measure the length corresponding to a degree at different points of the earth's surface. If these lengths be everywhere the same, we know that the earth is a sphere.

The following table contains the lengths in feet, thus observed to correspond to an angular inclination of the verticals of one degree at different places.

| | Feet. | | Lat. |
|---|---|---|---|
| Sweden . . . . | 365,782 | Svanberg . | 66⅓° |
| Russia . . . . . | 365,368 | Struve . . | 58 |
| England . . . . | 364,971 | Ray, Kater . | 52½ |
| France . . . . . | 364,572 | Delambre . | 45 |
| Rome . . . . . | 364,262 | Boscovich . | 43 |
| Cape of Good Hope . | 364,713 | Lacaille . . | 33 |
| India . . . . . | 363,044 | Lambton . | 16 |
| India . . . . . | 362,956 | Lambton . | 12½ |
| Peru . . . . . | 363,626 | Condamine . | 1½ |

It will be perceived that these admeasurements range from sixty-six degrees of latitude, or within twenty-four degrees of the pole, to within one degree of the equator, and that they are made not all in one meridian, but in different positions round the earth, and yet they all agree in giving for the length of the portion of its surface, lying between two verticals which contain the same angle of one degree, within five hundred yards of the *same* quantity, viz., sixty-nine miles and one-tenth. Hence, then, it follows, that since lines drawn in different places from its centre, making the same angles with one another, intercept portions of its surface nearly equal in length,—it is very nearly a sphere. Its real form is that called by geometricians an oblate spheroid, being something of the flattened form of an orange, the flatness being about the poles, but exceedingly small, so that its greatest diameter only exceeds its less by about 26½ miles, the one being 7925·648 miles, and the other 7899·170 miles.

## VIII.

### The Motion of the Earth.

It has been shown that the earth is a huge isolated mass, having no contact with any other, but self-supported in space.

Now it will at once occur to the reader, that a mass, placed under these circumstances, whose surface had no other contiguous surface to rest against, no fixed pedestal or suspending chain to keep it in its place, would necessarily *move*, if any external force were applied to it. And those who have studied the theory of mechanics know further, that any motion thus communicated to it would, since there is no friction or other opposing resistance to destroy it, continue FOR EVER. And that this is true as to the *fact*, however great or however small may be the amount of the disturbing force, varying only in this respect as to the *degree* of the motion. It will occur to them, therefore, as quite possible, that this ball should be, and should *have* been from all eternity, in motion, provided there be, or ever have been in existence, an external power capable of moving it. Nay, their speculations on the probability of the case may be carried yet further.

It is a principle of mechanics, that if motion be communicated, by impact or otherwise, to a mass in any other direction than *through* its centre of gravity, this mass, when left to itself, will have two motions, one a motion of translation, in which all its parts, including its centre of gravity, partake in common,—the other, a motion which will ultimately be a motion of rotation about a certain axis through its centre of gravity, in which only those parts of the body which are *without* this axis will partake. And it is a remarkable fact that these two motions of translation and rotation will be quite independent of one

another, so that the motion of translation will be precisely the same as though the mass had been struck through its centre of gravity, and there had been no rotation, and the motion of rotation the same as though there had been no translation, the centre of gravity of the mass having been held at rest. Thus, were the mass a sphere, and had it been struck otherwise than through its centre, it would necessarily spin round one of its diameters, and at the same time move forward in a straight line with a motion of translation. Also this spinning motion would be the same as if the axis about which it takes place had been kept at rest like that of a globe, and the motion of translation the same as though the ball had been struck through its centre, and had not therefore spun at all on its axis.

And all this is true, however slight the impulse which might be given to it.

To put this fact in a more striking light, let us suppose the force of gravity on the earth's surface for an instant to be *destroyed*, and let the reader be imagined to have constructed a sphere of clay, and having done so, to hold it up in his hand, and then to unloose his grasp from it. It would immediately begin to spin upon one of its diameters, and to move onward through space with an uniform motion, which would never of its own accord alter its direction, or cease. There being no force of gravity to draw it downwards, had no force whatever been communicated to it when it was set free, it would have *rested in space;* but it will have been found impossible to set it free from the hand without communicating some motion to it, and it is an infinity of chances that the direction of that motion shall not have been precisely through its centre; in which case there will, of necessity, have resulted a motion of translation, and one of rotation.

It is scarcely necessary to apply this illustration to the case now under our discussion: that the Hand by which the materials of our globe were brought together could have been

withdrawn, and yet that mass left *quiescent* in space no one ventures to deny; but that it should *move* is the simpler case, and that the same Hand, when it had spread upon the face of the earth its glorious covering of green herbage, of flowers, and of forest-trees, and sent forth the cattle on a thousand hills, should then have imparted to it that impulse in space, whence should result the alternations of day and night for the repose of every living animal, and the periodical changes of heat and cold, whereby every variety of vegetable life should be made to bring forth its fruit in due season, is by far the more probable of the two suppositions.

That this earth, then, which we *know* to exist, isolated in space, should be in motion, that it should revolve continually and uniformly round one of its axes, and at the same time with a motion of translation *forward* in space, will not seem improbable. In fact, it is seen on the whole to be more probable than that it should be at rest.

Let us now consider the matter in another light. In a former chapter, an observer was supposed to set out from the north, and travel southward round the earth; and it was shown that the horizon of such an observer must (to explain the phenomena) be supposed continually to roll with him, causing by its angular *approach* to some of the fixed stars as it thus rolled along, and its recession from others, an apparent approach of the stars northwards to the horizon, and their ultimate immersion beneath it, and the converse of all this, southward. Now, instead of his moving southward from the north, let us suppose him to move eastward from the west. His horizon now, as before, rolling along with him, those stars which are behind him will continually appear to descend upon the vault of the heaven behind him, and those before him to ascend; thus they will appear to rise to the eastward, to revolve over his head, and to set in the west. Let him now be supposed to move thus with such rapidity as to describe in twenty-four hours the whole circumference of the earth, and to continue this gyration uniformly and uncon-

sciously for ever. As his horizon is thus brought continually into different positions, with reference to the stars, and as he does not suspect the fact of the motion of his horizon, he will necessarily suppose the stars themselves to take up different positions with regard to the horizon, to ascend from beneath it, pass over the space above it, descend again beneath it, and every twenty-four hours to make a complete revolution about him. Now, instead of the observer thus careering continually round the earth, let us suppose him to remain at rest, and the earth itself to move, carrying him round with it. The appearances of the heavens will manifestly be to him exactly the same as before.

The only difference of the cases is this; instead of the observer having in every position a new horizon, occupying a different situation with regard to the region of the fixed stars, he will have everywhere the same horizon, which will be made to occupy in succession precisely the same positions as his *different* horizons did on the former supposition; and being here, as before, unconscious of the motion of his horizon, he will attribute the apparent ascent of the stars to the eastward, and their descent westward, to a proper motion of the stars themselves, and not to its true cause, the alteration of the position of his own horizon with respect to them.

Thus, then, if the earth carried us round perpetually in space as it spun upon its axis, looking at the stars we should observe precisely the same phenomena as those which the appearances of the heavens daily present to us. The heavens would appear to turn round us. We have then to choose between two hypotheses, which equally well account for the observed facts of the apparent daily rotation of the vault of the heavens; these hypotheses are, that the host of heaven do daily revolve with a common motion round us, or that the earth revolves daily and uniformly round one of its diameters.

We have shown this last hypothesis to be in a high degree probable from the fact, that the earth is a mass, separated and

isolated from all others, and, as it were, self-supported in space; certain, therefore, to retain any motion communicated to it, and if that motion were communicated otherwise than through its centre, certain to revolve for ever upon one of its axis, as well as to move forwards.

Now let us consider the probability of the other hypothesis, viz., that the heavens and all their host do really revolve round us every twenty-four hours as they appear to do. It has been shown in a preceding chapter, that the region of the fixed stars is distant from us by a space not less than one hundred thousand times the earth's diameter—in reality it is far more remote than so many times the diameter of the earth's orbit. Being thus distant, the magnitudes of the fixed stars must be enormous, or we should not be able to see them.

The hypothesis of a daily revolution of the heavens amounts then to this, that millions of immense bodies, stars innumerable, revolve each in its particular orbit, and each with a velocity greater than that of light round one of the axes of this earth of ours, which is but an atom in comparison with the least of them. There is a limit somewhere placed, beyond which that which is improbable merges in that which is impossible, and this hypothesis seems to pass it.

The improbability may, however, yet be rendered stronger. The stars called fixed, because they preserve always the same relative positions, are not the only stars seen in the heavens: there are other bodies, whose apparent positions in reference to one another, and to the fixed stars, are perpetually changing, "Palantia sidera cœlo." Besides, then, their daily revolution with the rest of the heavens, these must, if our hypothesis be true, have a continual motion among the other stars, and this of the most perplexing and extraordinary kind. The sun, for instance, must be supposed, besides his daily motion, to move in the same direction completely through that girdle of stars called the zodiac, once a year; and the moon once a month. The planets

Mercury and Venus must be supposed always to accompany the sun in his motion, but sometimes to lag behind him, and at others, to press on before him, altering perpetually in brightness with each variety of motion. The planets Mars, Jupiter, and Saturn, must be supposed to have paths, subject to so complicated a law of change, as to appear to have their motions governed by a kind of caprice.

Sometimes we must suppose them to travel forwards on the vault of the heavens, then by an indirect and tortuous course to retrograde, at one time in opposition, at another in conjunction with the sun, thus presenting the image of a wandering, unsettled, reeling, and lawless course through the sky; and all this motion, which passes through its changes slowly, and by periods of months, we must suppose combined with the steady and regular daily motion, common to the whole region of the stars. The complexity of this hypothesis renders it next to impossible that it should proceed from the same Hand, of whose *economized* and *skilful* operation we find such abundant evidence in the things that surround us.

Now let us place the hypotheses together; on the one hand we have to suppose that these millions of stars, situated at immeasurable distances from our earth, and immeasurably greater than it, nevertheless whirl round it with inconceivable rapidity every twenty-four hours, and that besides this motion, certain of them wander perpetually through space in tortuous eccentric paths, subjected to some unknown and most complicated law of deviation.

On the other hand, take the hypothesis that the earth revolves upon its axis perpetually and uniformly, and at the same time moves forward in space, an hypothesis rendered in the highest degree probable by the fact, otherwise ascertained, of its entire isolation in space.

The improbability of the first hypothesis, infinite as it is in itself, is infinitely increased by the probability of the second.

But however conclusive may be this balance of probabilities, the question admits of a still more rigid determination.

In the first chapter were stated the circumstances which absolutely prove the stars to be material bodies like our earth, subject to the same laws of attraction and motion as what we see around us; and the same is ascertained with equal certainty in respect to the sun and planets of our system. Now this being the case, it is *impossible*, from the nature of these laws of attraction and motion, that this sun, these planets, and these immense and distant stars, should turn continually round our little earth.

If two bodies, subject to the known laws of attraction and motion, revolve freely in space, we know that their revolution must take place, not about the actual centre of gravity of either body, but about their common centre of gravity. Now the common centre of gravity of two bodies is nearer to the *greater* of the two; so that the point about which the two revolve is always nearer to the greater body; and if the one body be infinitely greater than the other, it is infinitely nearer to it. And thus the effect is precisely the same as though the less body revolved about a point coincident with the centre of gravity of the greater.

But the sun is infinitely greater than the earth.* The sun could not, therefore, if the earth and sun only were in existence, revolve round the earth, but the earth must revolve round a point infinitely near to the centre of the sun. And this result will scarcely be affected by the introduction of the other bodies of our system into the discussion;—the whole revolve about their common centre of gravity, which, by reason of the great magnitude of the sun, when com-

* The sun is about one million four hundred thousand times greater than the earth; Jupiter about fifteen hundred times; and Saturn about nine hundred times.

pared with any of them, is a point which may be considered as fixed, and which may be considered as exceedingly near its centre.

It is impossible, then, that the sun should revolve round the earth every twenty-four hours. And we must take the other hypothesis.

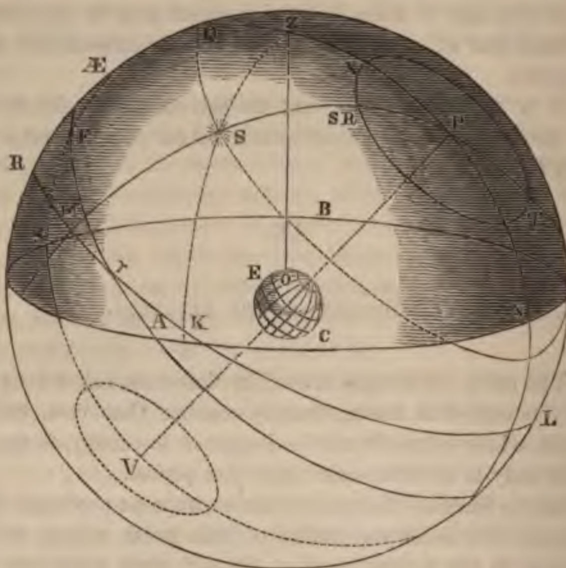
## IX.

### The Sphere of the Heavens.

The earth turns upon one of its diameters, called its axis, every twenty-four hours, thereby causing that vast, hollow sphere, whose centre it may be imagined to occupy, to appear continually to revolve round it in that period.

Let us imagine the axis of the earth to be produced both ways, so as to meet the surface of this great sphere of the heavens in the points P and V. It will thus mark out the two poles of the heavens, about which the stars appear to have their diurnal paths, of which one is represented by the circle X R T, in the figure.

Let the plane of the equator of the *earth* E C, be produced, to intersect the sphere of the heavens. The great circle, Æ Q, in which it will thus intersect it, will be the equinoctial. Any plane drawn through the axis, P V, of the heavens, will intersect the celestial sphere in a circle called a declination-circle, of which circles T P S M V, shown in the figure, is one. Declination-circles are those great circles which pass round the heavens from one pole to the other. Every point of the heavens is supposed to have one of these declination-circles passing through it. The use of them is to fix the position of any star on the vault of the heavens, in the same manner as the position of a place is fixed on the surface of the earth by its longitude and latitude.




If we know the particular declination-circle which passes through any star, and also the situation of the star on that circle, we have an accurate conception of the position of the star on the vault of the heavens. We can convey that conception to others, and by reference to a celestial globe, or to a chart of the heavens, we can tell what this particular star is, and what is its position in reference to other stars.

Each declination-circle passes through the poles of the heavens, and, of course, intersects the equinoctial, which lies midway between these poles at right angles. There is a particular point on the equinoctial, called the point Aries, marked in the engraving by the symbol ♈, the position of which in the heavens will be explained hereafter. The distance of the point where the declination-circle of any star cuts the equinoctial, from this point Aries, being measured eastward along the equinoctial, is called the RIGHT ASCENSION

of that star; and the distance of the star from the equinoctial, measured on its declination-circle, is called the DECLINATION of the star. Thus knowing the right ascension and declination of a star, we know its exact position on the great sphere of the heavens, and can refer to it on a celestial sphere or chart; for from the right ascension we know the position of its declination-circle, and from the declination, its situation on that particular declination-circle. Thus, in the figure, the declination-circle, T P S M, which passes through the star S, intersects the equinoctial in the point M; the distance ♈ Q Æ M, of this point from ♈, measured eastwards on the equinoctial; Æ Q, is therefore the right ascension of S, whilst the distance S M, measured on the declination-circle, between S and the equinoctial, is the declination of S.

If the plane of the meridian of longitude of any place on the earth's surface be continued to the celestial sphere, it traces out there what is called the celestial meridian of that particular place. Thus, if O be any place on the earth's surface, and if the plane of the meridian of longitude passing through O be produced to intersect the sphere of the heavens, the circle in which it will intersect it is the celestial meridian of O; it is represented in the figure by the circle N P Z S F V; the dotted line being supposed to represent that portion of the circle which is behind the figure.

Since the earth is continually *revolving* in the position which it apparently occupies in the centre of the celestial sphere, the celestial meridian of each particular place is continually revolving over the face of the heavens, about the axis of the heavens, coinciding in succession with all the declination-circles in the course of twenty-four hours. This is the *real* state of the case. The *apparent* state of the case is, however, precisely the *opposite* of this. The place of the observer appears to be fixed, and therefore his celestial meridian to be *fixed;* whilst the stars, and with them their

declination-circles, appear to revolve every twenty-four hours, each declination-circle coinciding in its turn with his *celestial* meridian.

When the declination-circle of any star thus coincides with the celestial meridian of any place, the star is said to be *on* the meridian of that place, and its altitude at that moment above the horizon is called its meridian altitude.

The plane of the celestial meridian passing through the axis of the earth passes through its centre, and is perpendicular to its surface. A line perpendicular to the earth's surface at any point, is, therefore, in the plane of the meridian at that point, and such a line being produced to the heavens, will intersect them in a point of the meridian of the place.

Thus the vertical, O Z, at any place, O, on the earth's surface, being produced to the heavens, intersects them in the celestial meridian, N P Z, of the place. The point Z, where the vertical intersects the sphere of the heavens, when produced upwards, is called the Zenith; when produced downwards, the Nadir. The Zenith is that point of the heavens which an observer sees immediately above his head; the Nadir, that point which he would see if nothing intervened immediately beneath his feet.

The celestial meridian of any place has been shown to pass through its zenith. Also, by the definition of it, it appears that it passes through the poles of the heavens. The celestial meridian of any place is thus a great circle drawn through its zenith and the poles of the heavens. The points where this circle meets the horizon are called its north and south points, and the points of the horizon half-way between these, its east and west points. Thus, if N B S A be the horizon of an observer at O, the points N and S, where the celestial meridian of that place intersects it, are its north and south points, and A and B, half-way between these, its east and west points. If a great circle, Z S K, be imagined to be drawn from the zenith Z, to the horizon, through any star S,

it is called the azimuth circle of that star: K S is its altitude, Z S its zenith distance, and N K its azimuth.

## X.

### TO DETERMINE THE LATITUDE OF A PLACE ON THE EARTH'S SURFACE.

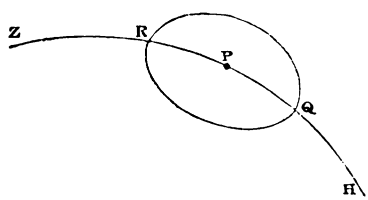
Let P represent the pole of the heavens; Z, the zenith of an observer on the earth's surface at E; P Z Q S H, a great circle of the heavens passing through these points: this circle is,


therefore, the meridian of the bserver at E. Let H K be the horizon of the observer at E, at right angles to Z E; also let R S be the equinoctial, at right angles to the axis P Q of the heavens. The earth, E, may be considered as a mere point, in comparison with the sphere whose centre it occupies. Now the celestial meridian, P Z K S, being in the same plane and concentric with the *terrestrial* meridian of the observer, the arc, Z R, between the equinoctial and the zenith, contains as many degrees as does the arc, E F, of the *terrestrial* meridian between the equator and the place of observation. In fact, these arcs measure the same angle at the earth's centre. But the arc E F, of the meridian intercepted between the equator and the observer's place, is his latitude; the arc, Z R, between the equinoctial and the zenith, is, therefore, equal to the latitude. And if we could but see exactly where the equinoctial was in the sky; if it were marked, for instance, upon it as it is upon our globes, by a band stretching across the heavens, we could at once determine the latitude of any place by measuring the distance upon the meridian between this band and the zenith of the place.

But although we cannot, without much difficulty, fix the position of the equinoctial in the heavens, the pole is much more readily found; and this will answer the same purpose, for the arc, Z R, is equal to P H; therefore the arc, P H, which is the distance of the pole from the horizon, or the elevation of the pole, as it is termed, is equal to the latitude of the place of observation. Here, then, is a very simple method of determining the latitude. We have only to observe the altitude of the pole of the heavens above the horizon.

But there is still another difficulty; for the pole of the heavens cannot at once and accurately be found. The polar star is usually said to be in the pole of the heavens; whereas it is, in reality, distant from it by about one degree and a-half.

How then shall we find the exact height of the pole, not being able to distinguish its place in the heavens. *Thus;* let us fix upon one of those stars which are not so remote from the pole as to be made by their revolution round it, to sink beneath the horizon, and are, therefore, called circumpolar stars.

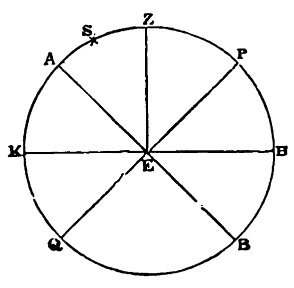



Let R Q represent the diurnal path of one of these about the pole, P; also, let Z R H be the celestial meridian of the observer.

Let the altitude of the star be observed when it is on the meridian at R, at what is called its *superior* passage over it, and also when at Q, at the time of its *inferior* passage; the altitudes H R and H Q being thus known, exactly half their sum will be H P, the exact height of the pole P.

Take, then, half the sum of the two meridian altitudes of a circumpolar star, and you will obtain the altitude of the pole, that is, the latitude of your place of observation. It is clear that the star is at its highest point when at R, and at its lowest at Q. The rule, then, may be expressed thus: "Take half the sum of the greatest and least altitudes of a circumpolar star, and the result will be the latitude." Thus it becomes unnecessary to know exactly what is the position of the celestial meridian. This is probably the most accurate method of finding the latitude.

The practical objections to this method of determining the latitude, are these,—it requires an interval of the half of a sidereal day between the two observations required, and it requires that the observer should remain in the same place during that interval. Now the latitude is sometimes required to be known at once, and, as in the case of a ship at sea, the same place cannot be retained during the interval in question. Again, these are observations which can only be made at night.




The following method will obviate all these difficulties.

Let S represent the position of any of the heavenly bodies, a star for instance, or a planet, or the sun, or moon, when on the celestial meridian of the observer.

This celestial meridian, then, coincides with the declination-circle of the star, and the distance, A S, of the equinoctial from the star measured on the meridian, is the declination of the star. Now suppose the declination to be known (and the declinations of all the principal stars are known, and have been inserted in tables); also the declination of the sun, which alters daily, but, nevertheless, admits of being calculated for every day of the year; and is so calculated and registered

in the *Nautical Almanack.* Hence, therefore, the distance, A S, of the sun, or star, from the equinoctial, is *known* for every day in the year. Now, let the meridional distance of the sun from the ZENITH be *observed,* if the latitude be required to be found in the day-time; or the meridian distance of a known star from the zenith, if the latitude be required at night. Thus the distance S Z will be known by observation, and A S, the declination is known by the tables. The sum (or the difference, if S be on the other side of A,) of these, A Z, is the latitude. If it be more convenient to measure the distance of S from the horizon than the zenith, as is commonly the case, then from this meridian altitude of the sun, as it is called, its zenith distance, S Z, is at once found, by subtracting it from Z K, which we know to be 90°.

It need scarcely be suggested, that when the altitude of the sun is thus measured, it must be the altitude of the *centre* of his disc, it being the centre of the sun's disc of which the declination is given in the tables.

Some of the most simple, and at the same time some of the best, of the numerous methods for determining the latitude having been explained, let us now consider how that other element requisite for ascertaining the place of the observer on the earth's surface,—the longitude, may be found.

## XI.

### To determine the Longitude of a Place on the Earth's Surface.

The motion of the earth upon its axis is UNIFORM; hence, therefore, it follows, that the celestial meridian of every place on the earth's surface is swept over the face of the heavens with an *uniform* motion. Since the earth revolves in $23^h\ 56'\ 44{\cdot}09''$ or nearly twenty-four hours, *completely* upon its axis, that is, through 360°, the meridian of each

place travels the heavens at the rate of about 15° an hour.—The reader must here bear in mind that the earth is supposed to be revolving in the centre of a fixed hollow sphere, and that the celestial meridians of places on the earth are great circles of this great outer sphere, revolving round the axis of the heavens with those places on the earth's surface to which they severally belong, and thus coinciding in succession with the declination-circles which are *fixed* on the *concavity* of the sphere.—Now, let us suppose one of the *terrestrial* meridians of longitude to pass through each degree of the equator: for each of these *terrestrial* meridians there will be a corresponding *celestial* meridian, and each such celestial meridian sweeping the heavens at the rate of 15° per hour, fifteen of them will pass over the same point of the heavens every hour, and generally the celestial meridians will pass over the same point in the heavens, the same star, for instance, (the same sun, or the same planet,) at the rate of 15° per hour. Hence, therefore, if the times at which the celestial meridians of two places coincide with the same star, differ by one hour, we know that the terrestrial meridians to which they belong are 15° apart, or that there is 15° difference of longitude between the two places.

Thus, then, if there were two observers at two different places on the earth's surface, and they had clocks set exactly to the same time; then, if each observed the time by his clock of his celestial meridian passing over a certain star (that is, of the star apparently coming on his meridian), then the difference of these times, or the interval shown by the clocks between them, would show the number of degrees of longitude which intervened, allowing at the rate of 15° per hour, or a degree for every four minutes of difference of time. If one observer, for instance, found that the star came on his meridian at eleven at night by his clock, and the other saw it at twelve minutes past eleven by *his* clock, then they would know that there were 3° difference of longitude between the places of observation.

The actual longitude of a place is the number of degrees of longitude intervening between it and the meridian of the observatory of Greenwich. Hence, if one of the observers of whom we have spoken were at Greenwich at the time of his observation, the difference of longitude deduced from the two observations would be the actual longitude of the place of the second observation. The inconvenience of this method is manifestly this;—that the two observers would be obliged, however remote their stations, to come together and compare their results, before anything would be known.

Now, instead of two observers, let us suppose one of them to have observed at Greenwich the time when the meridian passes over a particular star, by a clock set to sidereal time,—that is, so set that the hand revolves precisely twice round the dial-plate in the time which intervenes between the transit of the meridian over a star and its return to it, which time is always the same,—he knows, then, that the meridian of Greenwich will always return to the star precisely at the hour thus shown by his clock. Let us suppose it to be ten o'clock. Let him now set out to some other place westward, taking his clock with him. Let him thus travel for six months, and after that time wish to know into what longitude he has got. He has only to observe at what hour by his clock his meridian now passes over the star which he observed at Greenwich. Suppose it one o'clock at night. If his clock has gone right during the intervening six months, he knows that the meridian of Greenwich passes that night over the star at ten o'clock, that is, three hours before; allowing, therefore, 15 degrees of longitude an hour, it follows that he is 45 degrees west of Greenwich.

Now this is precisely the way in which the longitude is commonly found at sea, except that it is not pendulum-clocks which are used there, these being of course subject to injury and derangement, from the motion of the ship, but CHRONOMETERS, which are now constructed so as to go with wonderful accuracy, under every change of circumstances and tem-

perature. Instead of one chronometer, several are usually taken in the same ship. So that if any one by chance go materially wrong, the error will be detected by its disagreement with the others. Chronometers are commonly set, not for sidereal time, but for mean solar, or common time; but then the difference between this and sidereal time being known to be 3′ 55·9″ daily, it is very easy to ascertain what the sidereal time is from the common time.

By observations on the stars, the longitude can only be ascertained at night. Now it is frequently very desirable to find it by day.

How shall this be done?

The principle on which the determination of the longitude by means of a star is founded, is this, that we know the time when the meridian of Greenwich passed over the star, and observe when our own passes over it. Now suppose we know when the meridian of Greenwich passed over the sun, and observe when our own meridian passes over the sun, it is evident that we shall know, making the allowance of 15° per hour,* precisely as before, what is the difference of longitude.

But how can we tell at any remote place *when* the meridian of Greenwich on that day passed over the sun? If the meridian came back to the sun every day after the same interval, that is, if the solar days were all of the same length, there would be no difficulty whatever in this; we should only have to set our chronometer to solar time—put the hand at twelve o'clock, when the sun was on the meridian at Greenwich, then travelling anywhere else, we should know that if the chronometer kept correct time, when the hand was again at twelve the sun would be on the meridian at Greenwich. And if we observed what time was shown by it when the sun was upon the meridian at the place of our observation, the difference between this and twelve o'clock, allowing

* Making also a small allowance for the apparent motion of the sun.

one degree for every four minutes of time, would give us at once the longitude. But the sun does not return to the meridian on *any* two successive days, after precisely the same interval; so that the chronometer, whose hand returns to twelve *precisely* after the same interval, cannot show for any two successive days the precise time of the sun's passage, or rather of the passage of the meridian across it; thus our chronometer will not show us truly the time of the meridian transit at Greenwich, and our method fails. How then shall we get over the difficulty? Thus;—the difference between the mean solar time of noon, or twelve o'clock, and the time when the sun actually comes to the meridian, may be previously calculated for every day in the year, and it is so calculated and registered in the *Nautical Almanac*. Hence, therefore, if we have a chronometer set by Greenwich, which keeps true mean solar time, we can tell by reference to the almanack how much before or past twelve o'clock it is by that chronometer when the meridian of Greenwich passes over the sun; and observing when the meridian of the place where we are passes over the sun, we have the difference of the times of the two transits, and allowing $15° 2' 27{\cdot}847''$ for every hour, or $15' 2{\cdot}641''$ for every minute of this time, we obtain at once the longitude of the place. The reason why we now allow somewhat more than 15° for the motion of the meridian per hour is, that now our chronometer shows mean solar time, whereas before, we supposed it to show sidereal time. The nature of this difference will shortly be explained. But first it will be well to point out certain methods by which the longitude may be determined, which do not depend for their accuracy, as these do, upon the rates of chronometers. It is very important to have such means, because, after a long period of time has elapsed, it is scarcely possible but that the greater portion, if not all of the chronometers, may have failed, and the true time have been lost. Or it may be necessary to determine the longitude of a distant

place with greater precision than any chronometer can possibly give it.

All that we want to determine is, on any day, when we are at a distant place, the precise moment when the meridian of Greenwich passed, that day, over the sun. Now suppose that precisely at that moment they threw up a rocket at Greenwich which we could see at the place of our observation: this would completely answer our purpose; for looking at the clock when we saw this rocket, and observing the precise moment by the same clock when the meridian, where we are, passes the sun, the difference of these times, properly reduced, will give us the longitude. This rocket need not, however, be thrown up precisely at the moment when the meridian of Greenwich passes over the sun. Provided it be agreed on or known before precisely how many hours, minutes, &c., it is before or after the meridian transit that the rocket will be thrown up, we are manifestly just as well able to tell what was the precise moment of transit as though the rocket went up when it actually took place.

Well now, instead of the throwing up of a rocket, let us suppose that the astronomer at Greenwich could put a screen over the moon, or over one of the satellites of Jupiter, precisely at a number of hours before or after the transit of the sun at Greenwich, which number of hours was known and agreed upon beforehand. This phenomenon, wherever it was visible, would answer the purpose of the rocket, and enable us to tell the time of the transit of the meridian of Greenwich; comparing which with our own, we should know the longitude.

Now this is what actually occurs, except that it is not the hand of the Astronomer, but that of God which, at appointed seasons, brings darkness upon the face of the moon, and causes, night after night, one or other of the satellites of the planet Jupiter to plunge into his shadow. The precise number of hours, minutes, and even seconds, before or after the transit of the sun at Greenwich, when these phenomena

occur, are calculated and registered in the *Nautical Almanack;* and any one observing them at ever so distant a place can tell thus the time of the sun's transit at Greenwich, and observing his own he can thus find its longitude.

The eclipses of the sun or moon occur but rarely, so that an opportunity of finding the longitude by them, although certainly the best, is very seldom presented to us. The eclipses of Jupiter's satellites occur almost nightly, and these answer every purpose of finding the longitude on land. But at sea this method fails, for it is impossible to hold a telescope of the required length sufficiently steady on ship-board to see the satellites of Jupiter.

In the failure of these methods, another of great ingenuity has been contrived—a method which, in its practical application, simplified as it is by the use of tables, presents little or no difficulty, but which, in the researches on which those tables are based, constitutes one of the greatest triumphs that the human intellect has, in our times, achieved.

The moon does not rest among the fixed stars, but moves along that band of the heavens which is called the zodiac; and it moves with a comparatively rapid motion, describing the complete circuit of the heavens in $27^{d}\ 7^{h}\ 43'\ 4''$, or moving at the mean rate of $13°\ 10'\ 35''$ a day, and $32'\ 56{\cdot}46''$ per hour. Thus, then, the moon is in no two successive hours at the same distance from any one of the fixed stars, nor, indeed, in any two successive minutes. Suppose, now, that the time after or before the sun's transit at Greenwich, when the moon would be at a given angular distance from a certain fixed star, were calculated, and inserted in the *Nautical Almanack*, and that an observer at a distant place, having that almanack, were to observe when the moon was at that angular distance from the star, (an observation which he could very readily make, even on ship-board, by means of an instrument called a sextant,) he would know precisely how far the moment when this observation was made, was from the time of the sun's transit at Greenwich; and having ob-

served when the sun's transit took place with him, he would thus, as before, have the difference of longitude.

## XII.

## The apparent Complexity of the Problem of the Heavens.

One of the most involved and complicated problems ever proposed to the ingenuity of man, was the problem of the Heavens. A hollow concave about him, the whole of whose surface, go where he may, is apparently at the same comparatively small distance from him; the sun taking his journey across it, in a path which is not daily the same; returning day after day, through some unknown region, to flood again the vast canopy of the heavens with light; stars seen in thousands at night, on this vast canopy, moving with one common motion slowly across it, between night-fall and day-break; this host of stars, different at different seasons of the year, but the same at the same season, preserving, in the *general* alteration of their position, their *relative* distances, except six of them, which wander about among the rest with a most devious motion, and are therefore called planets; the moon, too, moving with the common daily motion of the rest of the host of heaven; but, besides, revolving completely through it every month; Winter, Spring, Summer, and Autumn, connecting themselves somehow with the variations of the daily path of the sun, and returning, year after year, at their appointed seasons; and eclipses of the sun and moon, dependent by some inscrutable relation upon relative positions of the sun and moon;—all these things requiring, as they must have done and did, a great length of time, and much and patient observation to *discover*, constitute, in their aggregate, a relation of phenomena which as far sur-

passes any other offered to us in nature in its complication, and the vastness and dignity of the truths which it embraces, as in the simplicity of the scheme into which it resolves itself.

The sphere of the heavens has been hitherto spoken of as fixed and immovable in space; and as having in its centre the EARTH,—of dimensions infinitely small and evanescent with regard to it—rolling perpetually round one of its own diameters, but never moving its centre from that of the great quiescent sphere of the visible heavens. The reader is now about to learn that this description of the position of the earth in space is incorrect:—that it does not occupy continually the same position in the centre of the sphere of the visible heavens—that its centre, and the axis within itself, about which its revolution takes place, are not at rest—that these are, in fact, moving at the rate of about 19 miles in each second of time—that this motion is not directly forward in space, but continually round in a curve which returns into itself, and which is very nearly a circle, whose radius is ninety-five millions of miles—that nevertheless this enormous circle of the earth's revolution is itself as nothing in its dimensions compared with the dimensions of the great sphere of the visible heavens, so that the motion of the earth from the centre of that sphere, may be considered evanescent as compared with the radius of the sphere, and everything which occurs with regard to the fixed stars, as occurring precisely as it would occur if the earth's centre were really quiescent in space. Thus, then, whatever has been argued from the *appearances* of the fixed stars, on the hypothesis of the quiescence of the centre and axis of the earth in space is accurate, although this hypothesis be false.

Besides the stars called fixed, because they retain always their positions with respect to one another on the sphere of the heavens, there are other bodies visible on it, whose position does not appear to be fixed, either in reference to one

another, or to the fixed stars; these are the sun, moon, and planets,—these, it will now be shown, lie greatly nearer to us than the fixed stars, and thus, within that great sphere which has been hitherto designated the sphere of the heavens—they describe enormous ellipses in space, which are yet so small in comparison with the dimensions of that sphere, that they may be considered scarcely to deviate from its centre. Thus infinitely great in themselves, but infinitely small in comparison with the distance of the stars, these ellipses are all described round one common focus, very near to which lies the centre of the sun.

The process of reasoning by which the complicated apparent motions of the sun, moon, and planets, are made to resolve themselves into these few real and elementary motions, is one of the highest and most successful efforts that has ever been made by the intellect of man.

If the heavens be watched from night to night, we have before remarked that, a continual alteration of the positions of the planets among the fixed stars will, from such observations, continued for a few nights, be very plainly perceived; the planet, Jupiter, for instance, being seen one night in the neighbourhood of a particular fixed star, will on the next be found to have slightly receded from it; the space of a week will produce a very marked separation, a month will have taken it completely away from it, and a year will probably have carried it into some opposite quarter of the heavens. Into the discussion of these apparent motions of the planets, which are very remarkable, we shall not at present enter. It is enough here to state the fact, that there are such motions, and that they do not take place irregularly and towards all parts of the heavens, but that they are, for the most part, confined to a certain zone or belt of it, about 18° in width. This zone, or belt of the heavens, is called the zodiac. A line drawn along its centre would be a great circle of the heavens, and would cut the equinoctial at an angle of 23° 28′.

The moon, too, takes her wandering solitary course eastward along this zone of the heavens. And her broad disc is continually seen covering and passing over the stars which lie along her path. Her motion, although somewhat irregular, is very rapid, being upwards of 13° in 24 sidereal hours, or nearly half a degree every hour, so that she may almost be *seen* to move among the stars.

## XIII.

### The Apparent Annual Revolution of the Sun through the Heavens.

Now the question at once suggests itself, does the sun too move, or appear to move, over the concave of the heavens in which he, as well as the moon, occupies a place, or does he remain in a fixed position among the stars? This question cannot be determined in reference to the sun, as we determine it of the moon—we cannot *see* the sun's motion among the stars, *for when the sun is up, the stars are to the naked eye invisible*;—how is it then determined? Thus: If the sun were apparently fixed like the stars, the time intervening between the passage of the meridian of any particular place over the sun, and its return to the sun again, would evidently be precisely equal to the time of its passage over a fixed star and its return to that fixed star again. Now, this is not the case. One of these periods is called a solar, and the other a sidereal day, and the solar day is not of the same length with the sidereal day; it is always longer than it; that is, the celestial meridian of any place on the earth's surface always revolves from a fixed star to that star again, sooner than it revolves from the sun to the sun again. The sun, then, does not remain, or appear to remain, fixed like the stars, on the sphere of the heavens, it moves in the same direction in

which the meridian moves, the meridian arriving at the place in the heavens where the sun was on the preceding day, before it arrives at the sun. Now the meridian revolves, with the earth, eastward; the apparent motion of the sun on the sphere of the heavens is therefore *eastward*.

And, moreover, the amount of this daily motion of the sun eastward may readily be found; we have only to subtract a sidereal day (that is, the time which the meridian occupies in revolving from the sun on one day to the same place in the heavens on the next) from a solar day, or the time of the revolution of the meridian from the sun on one day to the new place which the sun occupies in the heavens on the next day. The difference will be the time which the meridian has occupied in revolving from the sun's place on the preceding day to its place on this day: this difference will be found different for different days in the year, but its average is $3' \, 56\frac{1}{2}''$ of sidereal time. This, then, is the mean sidereal time which the meridian occupies in revolving from the sun's place on one day in the heavens to its place on the next day. Now the meridian revolves through the whole 360° of the heavens in 24 sidereal hours, or over 15° of it in one sidereal hour; it revolves, therefore, as may readily be found by the rule of three, over an arc of $59' \, 8''$ in this $3' \, 56\frac{1}{2}''$ of time; and therefore the sun's place on the second day is $59' \, 8''$ more to the east than on the first day, or its daily motion is $59' \, 8''$ eastward. But an arc of $59' \, 8''$ being multiplied by $365\frac{1}{4}$ will give us 360°.* In $365\frac{1}{4}$ days, therefore, the sun will have revolved eastward on the sphere of the heavens through 360°, that is, completely *round* it—THIS PERIOD IS ONE SIDEREAL YEAR.

The sun, then, although we cannot see him moving on

* Within about one minute and a half. The true length of the sidereal year is, 365·256312 days, and the mean daily sidereal motion of the sun is $59' \, 8{\cdot}19''$ nearly.

the heavens, there being no fixed object visible upon them when the sun can be seen to which we can refer his motion, does yet present the same phenomena as though he moved continually like the moon eastward among the stars, except that instead of completing his revolution, as the moon does, in one lunar month, his gyration takes him a whole year.

But what path does he describe in the heavens? He revolves round them; but in what route? As we cannot see him among the fixed stars, how shall we find out his course? Thus:—We may find out, as is now to be shown, what declination-circle he is on for every day of the year at noon, and also we may find what is his declination, that is, we may find where he is on his declination-circle. Knowing these two elements, we shall know his exact position on the sphere of the heavens, and referring to a celestial globe or chart, we shall be able to tell what stars are in his neighbourhood.

The declination-circle on which the sun is, may be found thus:—let the exact time of the meridian passing over the sun's centre on any day be noted—now that meridian we know will return to its place in the heavens, or revolve through 360°, in 24 sidereal hours; it will therefore revolve through 180° in 12 sidereal hours. Let us then observe what stars the meridian is passing over precisely 12 sidereal hours after our first observation; we shall know that these stars are 180° from the sun's place on the preceding noon: counting, therefore, off 180° westward on the equinoctial of a globe, from that declination-circle on which are these stars, we shall know that the sun was on the declination-circle, which passes through the point which we thus find, on the preceding noon.

Again, to determine the declination of the sun, or *his place* on this declination-circle, we have only to find, by observation, his meridional zenith distance, Z S, and subtract it from the latitude, Z H, the remainder will be the declination, H S, of the place of observation.

Finding thus the declination of the sun, and the position of his declination-circle for the noon of every day in the year, we can mark on the celestial globe his position for every day, and joining these positions, we shall obtain his path on the sphere of the heavens. Now, all this has been carefully done, and the


apparent path of the sun among the fixed stars, thus found, is traced on all our celestial globes. The sun is thus ascertained to have, in common with the moon and planets, its path, called the Ecliptic, along that zone or belt of the heavens which we have called the zodiac; it is a great circle of the sphere, constituting, in point of fact, the *centre* of that belt, which stretches 9° on either side of it. The ecliptic is inclined to the equinoctial, at such an angle, that at the greatest separation of these circles there are 23° 18′ interval between them, measured on one of the declination-circles of the sphere. Along this path in the heavens the sun would appear to us to move, as the moon does, among the fixed stars, were it not that, by reason of his superior brilliancy, the stars are invisible to the naked eye so long as he is above the horizon.

The sun and moon both, then, have an apparent motion round the earth, the one in a year, and the other in a month. It is now to be shown that this *apparent* motion of the sun round the earth is *not* a *real* motion of the sun; but that it *results* from a real motion of the earth round the sun; and further, that the apparent motion of the moon *is* a real motion, resulting from an actual monthly revolution about the earth.

## XIV.

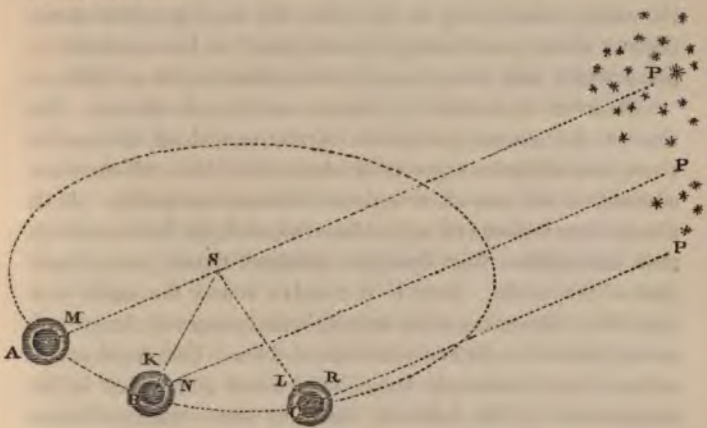
### The Annual Revolution of the Earth.

In the first place, then, it is asserted that a real motion of the earth round the sun would produce precisely those appearances which we observe in the heavens, and which have been attributed to an annual motion of the sun along that line which has been called the ecliptic.

Let A B C be positions of the earth, in an orbit which it is supposed to describe about the sun, which positions let it be supposed to occupy, at intervals each of a sidereal day. Also let A P, B P, C P, be lines drawn from a certain fixed star to a particular place on the earth's surface. Since the star, P, is infinitely distant, the lines A P, B P, C P, may be considered parallel. Suppose the meridian, M, of this place to be—in the position A of the earth—in the act of passing over this star; then, since there is an interval of a sidereal day between the positions A and B, the meridian of the same place will be passing over the star in the position B, and similarly in the position C. Now, let S be the sun, supposed to lie about the centre of the earth's orbit, and at a finite distance from it as compared with the distance of the fixed stars. Let the small sphere described round A, as a nucleus, represent the sphere of the visible heavens in that position of the earth, or let it represent that sphere to which a spectator refers the positions of all the heavenly bodies, and on which he imagines them to be distributed. And let the spheres round B and C be similarly interpreted. At A the observer, at the place which we have supposed, will see the star P on his meridian at M,* and the sun at the same time on the meridian; at B he will see the star at N, and the sun at K; and at C the sun will be

* He is supposed to have a telescope powerful enough to show him the stars in the day-time.

at L, and the star at R; thus, it is manifest that every time the star comes upon the meridian, the sun will appear to have receded further from it than at the preceding transit, describing arcs N K, L R, of a circle, formed by the intersection of the plane of the earth's motion with the surface of the visible heavens.




It will be observed, that although the spheres to which an observer refers the positions of the heavenly bodies, and which constitute his visible heavens, are, in different positions of the earth, different; nevertheless, they appear to him the same, because the stars which cover them by reason of their immense distance, do not alter their relative positions upon them. Thus, then, the sun will appear to describe a circle among the stars, which circle is, in point of fact, the intersection of the plane of the earth's orbit with that sphere of the visible heavens, which, in every one of its positions, appears to surround the observer. This circle being then supposed to be the ecliptic,—that is, the intersection of the plane of the earth's orbit with the sphere of the heavens being supposed to be the ecliptic,—all the phenomena of the apparent annual motion of the sun through this ecliptic are

explained by an annual revolution of the earth about the sun in that orbit.

Here, then, as in the case of the solar day, are two hypotheses, both of which explain the phenomena of the solar year: according to one, the sun revolves about the earth every year, in the middle of that band of the heavens called the zodiac;—according to the other, the earth revolves about the sun every year, having for the plane* of its revolution a plane which cuts the sphere of the heavens in the ecliptic.

Between these two hypotheses we have to choose. To that of the annual revolution of the sun about the earth, there are objections precisely similar to those which were adduced in the case of its apparent *diurnal* revolution. It is ninety-five millions of miles from us, and its bulk is more than one million four hundred thousand times greater than that of the earth. Now, if it revolve round the earth in a year, this huge mass must sweep through space at the rate of about 1200 miles in every minute of time. This rapid revolution of an immensely large body about one which is, in comparison with it, infinitely small, at once strikes us as an improbability; it is more than this, it is a mechanical impossibility, as will plainly be perceived when we come to treat of the laws of physical astronomy.

Again, such are the motions of those other bodies which we have called wandering stars or planets, and which we shall discuss hereafter, as incontrovertibly to prove that these revolve each in an orbit about the sun; also their magnitudes may be ascertained by direct trigonometrical admeasurement, and many of them are thus found to be greatly larger than the earth.† On the hypothesis we are discussing, not only, then, must the huge sun revolve continually with prodigious

* By the plane of the revolution of the earth, is here meant a plane in which are found all the lines drawn in different positions of the earth from its centre to the centre of the sun.

† Jupiter is 1500, and Saturn 900 times greater.

velocity about our earth, but the whole host of planets which accompany and revolve continually round him, and which are, many of them, as it respects magnitude, far more important elements of the material universe than our earth is, must, nevertheless, together with the sun, and in combination with their motion round it, sweep with it in a perpetual circle round the earth.

It is a curious fact, strongly illustrative of the waywardness and perversity of judgment of which we are all more or less the victims, that a philosopher, a laborious observer, and a man of considerable mathematical learning, was once found to take up this strange complicated hypothesis. The phenomena of the heavens were thus explained by Tycho Brahé, a Danish philosopher, the contemporary of Kepler, and the author of a very valuable catalogue of the fixed stars.

Again, (to accumulate all the evidence on this point) it has been shown that the earth has a *daily* motion upon its axis. Now, this fact of its daily motion renders also its annual motion highly probable. A probability founded on this other; that if there be two modes of explaining any phenomenon of nature, then, *cæteris paribus*, that is, the most probable which is the most simple. For by what we observe in the creation around, we are forced upon the conviction that the Almighty acts in this respect with that *economy* of creative energy, which, although infinitely more perfect in its degree, has nevertheless its visible type in that husbandry of *our* resources, that disposition to economy in *our* efforts, which impels us always to avail ourselves of the simplest possible means of effecting all that we wish to do.

Thus, when in reasoning upon any hypothesis, we are forced back upon secondary causes, it is sound philosophy to judge of the probability of that hypothesis, according to the simplicity or complication of the causes to which we are thus compelled ultimately to refer it. If, for instance, there be two hypotheses, by one of which, we shall be compelled

to fall back upon a double operation of the hand of the Almighty, whereas the other resolves into a single effort of his will, then is the latter hypothesis, according to the analogy of nature, more probable than the former, and that INFINITELY.

Now, as has been before explained, a motion of *rotation* having been communicated to the earth, it must also, in consequence of the force applied to communicate this motion, have had further a motion of *translation;* unless another, or second force, had been communicated to it in a direction through its centre, precisely equal to the first force, and parallel to it, but in an opposite direction. Thus, having, as it has, a motion of rotation, if in other respects it be at rest, the earth must, in the beginning, have had two distinct impulses communicated to it from without, in opposite and parallel directions, and at different but not opposite points of its surface.*

Again, this hypothesis of the quiescence of the earth in space, involves necessarily the revolution of the sun about it; a *third* impulse, therefore, must be supposed to have communicated this motion to the sun. Reasoning, then, upon the hypothesis of the sun's annual revolution, we are obliged to fall back upon three distinct operations of the Deity, whereas the opposite hypothesis of the annual revolution of the earth, subjects the whole of the phenomena to *one.*

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* It has been calculated by Bernouilli, that the single impulse by which the earth was made to revolve upon its axis in the time which we know it to revolve, and at the same time to move forward in space as we know it to move, must have been communicated to it in a direction perpendicular to the line drawn from it to the sun, at a distance further from the sun than the earth's centre is, by about the $\frac{1}{165}$ part of the earth's radius, or at a distance of about 25 miles further from the sun than the centre of the earth is. Similarly the impulse communicated to Mars must have been at a distance of $\frac{1}{414}$ of its radius from its centre—that of Jupiter of $\frac{7}{19}$, and that of the moon at $\frac{1}{160}$.

One *will*, one *impulse*, one development of the power of Him who spake, and it was done.

This argument, (and indeed every one of those which have yet been set before the reader) is, perhaps, in *itself* conclusive. Different arguments in proof of the revolution of the earth have been adduced rather because it may be considered necessary to a knowledge of astronomy, that the reader should be put in possession of all that has been said on the subject, than because it is thought that the arguments are in any way necessary to support one another. The accumulation of proofs, any one of which is sufficient, does not perhaps, in reality, constitute any accumulation of evidence; on the contrary, it is more according to experience to assert, that everything in the shape of proof which is added to that which is *already* proved, tends to weaken its authority. The evidence on this point is, however, too strong to be shaken by any method of arguing upon it, however illogical; yet another proof of the annual revolution of the earth will therefore now be added.

## XV.

### The Aberration of Light.

Whatever may be the true explanation of the phenomena of light, certain it is, that their origin and mode of operation is subject to the usual and known laws of mechanical action. The perception of light is the effect on *impulse*, somehow or another taking effect on the nerves which belong to the retina of the eye. Now this being the case, it is manifest that the effect of that impulse may be modified by the circumstances under which the eye is placed. If, for instance, the eye be at rest, the *effect* of the impulse on the eye and the resulting perception of light, will be in the same direction as that in which the impulse is made. If it be in motion, and the

velocity of its motion bear any finite relation to the velocity of the impulse of the light, then the effect on the eye, and the consequent perception of light, will not be in the direction of the impulse of the light, but in a direction compounded of the direction of the eye's motion, and the direction of the impulse of the light.

Thus, if a person standing *at rest* be struck by a ball obliquely from above, he will feel the blow in the direction in which the ball moves; but if he be in motion, the direction in which he feels the blow will be compounded of that of the ball, and that of his own motion.

We may thus ascertain what that compounded direction will be. Let us suppose a motion equal to that of the man to be communicated both to him and to the ball, at the same instant of time, but both in a direction precisely opposite to the man's actual motion, the same motion being communicated to both man and ball, the effect of the ball upon the man will not be altered by this motion thus added to it. But the man, having now impressed upon him a motion, equal and opposite to that with which he is already moving, will thus be brought to rest, and the ball will have two motions communicated to it, in virtue of which it will, by the known laws of mechanics, move in the direction of the diagonal of the parallelogram whose adjacent sides represent these motions; thus, then, its effect upon the man now brought to rest will be in the direction of that diagonal; also, by the hypothesis by which we have brought him to rest, we have not altered the effect of the ball upon him; restoring, therefore, the circumstances of our first hypothesis, the effect of the ball upon the man in motion, will be in the direction of the diagonal of the parallelogram, one of whose sides represents the motion of the ball, and the other the motion of the man.

If the direction of his motion be *towards* that from which the ball comes, the effect will therefore be in a direction still more inclined downwards, than the actual direction of motion of the ball, and if it be from that direction it will

be more inclined upwards. Thus let him be moving in the direction A C, so as to describe A C in one second of time,


and let the ball describe B A in one second of time. Then communicating to the ball and to the man the motion C A, equal and opposite to A C, the man will be brought to rest, and the ball will have the two motions C A and B A communicated to it, and will move in the direction D A. It is, therefore, in this direction, which is lower than its proper direction, that it actually takes effect. Similarly, if it had come from behind, in the direction E A, it would have produced its effect, when combined with the motion of the man, in the direction F A, which is *higher* than its proper direction. Now, for the impulse of the ball, let us substitute that of a wave of light, and let us suppose the spectator to be borne along with a velocity which has a certain finite proportion to that of the propagation of such a wave of light. The effect of the motion of the spectator on the direction in which the impulse of the light is perceived, will be precisely like that of the ball. If he is borne towards the object which is the origin of the wave, the direction in which the impulse is perceived will be lower, and if *from* it, higher than that in which it actually comes, and thus the objects towards which he is moving will appear *lower* to him, and those from which he is moving *higher* than they really are. If, then, the earth move in its orbit, and if the velocity of its motion bear any finite proportion to the velocity

with which the light of the fixed stars is propagated to an observer on the earth's surface, then those towards which the earth is moving in her orbit will always appear to him lower than they really are, and those *from* which she is moving, *higher*. And if she is *not* moving with any such velocity, then the light of the stars will appear to come to him in the direction in which it actually does come, and the stars will not appear higher when the earth's motion carries him from them, than when it carries him towards them. Now light travels at the rate of 192,000 miles per second, and the earth at about 19 miles per second. Thus, although the velocity of the earth bears but a small proportion to that of light, yet it does bear a certain finite and appreciable proportion. There will then be a finite and appreciable, though scarcely apparent depression, of those fixed stars towards which the earth is moving, and elevation of those in the opposite regions, provided the earth moves in its orbit as we assert; and if it do not, there will be no such depression or elevation. Now this difference of the true from the apparent position of the stars,—this apparent depression of those *towards*, and elevation of those *from*, which the earth is moving—does exist: it was discovered by Dr. Bradley, and is called the *aberration of light.*

## XVI.

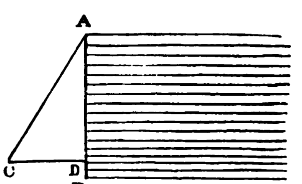
### The Distribution of Heat and Light on the Surface of the Earth.

There have now been placed before the reader those first truths of astronomy on which the whole fabric of the science may be considered to rest: the infinite distance of the region of the fixed stars, the entire isolation of the earth in space, its spherical form and huge dimensions, its *daily* revolution round one of its own diameters, and its annual revolution round the sun. In this chapter, some of those great

phenomena of the visible world which *result* from these will be brought under his consideration. First among these are the alternations of day, of night, and the changes of the seasons. The sun is the source of light and heat; these are facts of which the experience of every day of our lives constitutes the demonstration; they are so plain and palpable that no one was probably ever found to deny them. It is a matter also of daily experience, that a certain class of bodies called opaque, to which class belong by far the greatest number of the bodies around us, have the power of obstructing the light, and also, in a great measure, the heat of the sun; so that whilst the light and heat fall and exert their full influence on one side of them, the opposite is wholly deprived of that influence; the one side is then said to be enlightened and heated, and the other, where there is an entire absence of light and heat, to be in a state of darkness and cold, Now let us suppose a body thus opaque to be turned round, so that what was before the part turned *towards* the sun, may now be that *from it;* that part will be found to have retained none of the light which it received in its first position, so as to be now wholly and absolutely in a state of darkness; but it *will*, on the contrary, have retained a larger portion of its *heat*, so as *not* to be wholly and absolutely in a state of cold. Let us suppose the body a sphere; then will the enlightened portion of it be a hemisphere, that is, one half of the whole, and the division of the light and the

dark part of it will be a great circle, A C B D, of the sphere. If the sphere be turned round one of the diameters, A B, of this circle, the positions of its light and dark parts will eventually and gradually be interchanged,—the whole of what was dark before will now be light, and the whole of what was light before will be dark; and if the revolution of the sphere be continued *uniformly*, that is, always with the same velocity, then each point in it will continue as long on the light side as on the dark side,—as long on the side on which it *receives* heat, as on that on which it does not receive it. The quantity of light and heat which any point receives during the time of its revolution through the enlightened hemisphere is not, however, the same in all places on that hemisphere. Rays, as they are called, of light, and with them rays of heat, come in right lines; and from hence it follows, that any surface, presented perpendicularly to them, will receive and be acted upon by *more* of these rays than the same surface subjected to their influence *obliquely*. This will at once be rendered evident by a diagram.

Let A B represent a surface presented perpendicularly to the sun's rays; all those represented in the figure as lying between the points A and B will then take effect upon it. Now, let it be turned into the position A C, and let C D be drawn from C parallel to the direction of the rays; or perpendicular to A B. The rays lying between A and D are manifestly the only ones which now take effect upon the plane, those between B and D being lost. Thus, then, it appears that the same surface receives less light and heat when exposed obliquely than when exposed *directly* to the sun's rays; and the less as its position is more oblique.




Now, of the surface of the hemisphere of which we have spoken, only one exceedingly minute portion is exposed perpendicularly to the sun's rays; this portion lies about the

point Q, (see the cut on page 71,) where a tangent to the sphere is perpendicular to the direction of the rays. Every other portion of the surface receives the rays more or less obliquely, according as it is nearer or more remote from this one particular spot. It is manifest that there will thus arise a very unequal distribution of light and heat. In the revolution of the body, that portion which revolves through the point Q, will receive the greatest share; and those portions which are made by the motion of the whole to recede least from the edge of the enlightened hemisphere, will receive the least; thus if the sphere revolve about an axis going through A and B, it is about these points that there will be received in the aggregate the least of light and heat.

Now let us suppose the sphere, instead of revolving round one of the diameters of the circle which divides its dark and its enlightened hemispheres, to revolve round some other axis, as represented by A B in the accompanying figure. The dis-


tribution of the light and heat on the surface of the hemisphere will be precisely as before; but by the revolution of the sphere, the different parts of its surface will be made to partake very differently in it. Those, for instance, about the pole A will never, by the revolution of the sphere, be made to pass out of the enlightened hemisphere, whilst those about the opposite pole, B, will never pass out of the darkened hemisphere. Points of the surface situated about P will, by

the revolution of the sphere, be made just to pass *beneath* the boundary of light and darkness, whilst those about Q will only just be made to pass above it. Thus, in the one place, there will be the least conceivable portion of darkness, and in the other the least conceivable light. Between these extremes, and on the surface, extending from P to Q, may be found every conceivable proportion of light and darkness. The points nearer to P will be kept longer on the light side of the sphere than on the dark one, whilst those nearer to Q, will be kept longer on the dark side than the light. Now whilst any point of the sphere is receiving light, it is receiving heat, and when it is not receiving light, it is cooling, or giving out its heat. There is, therefore, every possible variety between P and Q, in the proportion of the periods during which heat is received and given out; and from this cause, if it operated alone, there would arise an exceedingly unequal distribution of temperature upon the surface of the globe, resulting ultimately from the fact of the axis, about which it revolves, not lying in the plane of the circle which separates its dark and enlightened portions. It is clear, nevertheless, that this cause of difference of temperature in some degree modifies that which has been before described as dependent upon the greater or less obliquity of the surface to the direction of the incident light and heat. Thus the parts immediately about the pole A, being more obliquely situated than those about the central portions of the sphere R, will on that account receive less heat. But then by the revolution of the sphere, these are never carried into the shadow,—they are therefore *continually* exposed to the action of the heat. Whilst about R each portion of the surface *receives* it only during a portion of its revolution, and throughout the whole of the remainder gives it out.

Thus, by this supposed position of the axis, the unequal distribution of temperature arising from different obliquities of the surface is in some measure remedied. And if the position of the axis in reference to the enlightened surface, or of

the enlightened surface in reference to the axis, were made to go through a state of continual change, this equalization of temperature might be carried on to almost any conceivable extent.

Now this is precisely the description of change which is going on continually on the surface of the earth, and from which result the seasons of our year.

The earth is a sphere composed of opaque materials: that hemisphere which is presented to the sun is enlightened and heated; and the opposite hemisphere is in the shadow, in cold and darkness. Being a sphere, the different portions of its surface are presented with different degrees of obliquity to the action of the sun's rays; and were the axis about which it revolves always in the plane which separates its enlightened and darkened hemispheres, or rather, did that plane always pass through its axis, then its revolution upon its axis would not in any way modify that unequal distribution of temperature which results from this difference of obliquity. Also, were the position of the boundary of the two hemispheres *fixed* in reference to the axis, supposing it *not* to be in the plane of that boundary, any accession of temperature thus given to certain oblique portions of the surface could only be so given at the expense of others. But in reality the position of the boundary of the dark and enlightened hemispheres is continually changing in respect to the earth's axis; and thus is brought about that distribution of temperature on its surface which is perhaps the most equable that can be conceived. The seasons are no more than a contrivance by which the unequal distribution of temperature resulting from the unequal obliquity of that portion of the earth's surface which is presented to the sun is equalized. This will be seen at once, when the way in which they are brought about has been explained.

## XVII.

### The Parallelism of the Earth's Pole.

The pole of the heavens always throughout the year, and from year to year, appears to retain the same place in the heavens, except that there is an exceedingly minute secular variation of its position called precession, and hereafter to be explained. Now, the pole of the heavens is the point in which the axis of the earth, when produced, in any of its positions, meets the heavens. Hence, therefore, it follows that the axis of the earth, in one of its positions in its orbit, and its axis in any other, include, when produced to the sphere of the heavens, a space which is imperceptible to us on the earth's surface. And from this it follows that its axis in one of these positions must be parallel to its axis in the other; for if they were ever so little inclined, being produced so infinitely far as the region of the fixed stars, they would include a perceptible space. In any one position of its orbit, then, the position of the earth's axis is parallel to its position in any other. This is usually expressed by saying, that in its annual motion the position of the earth's axis remains parallel to itself.

Not only is this a fact given us directly by observation, but it is also one resulting from the laws of mechanics, as applied to a material body, placed under the circumstances in which we know the earth to be placed.

Did no force whatever act upon it besides that which was *impulsively* communicated to it in the beginning, and from which has resulted its motions of rotation and tangential translation,—it is certain that moving continually forward in the same straight line in space, it would also revolve continually about the same axis within itself, and that this axis would retain its parallelism. Also, if in addition to the first

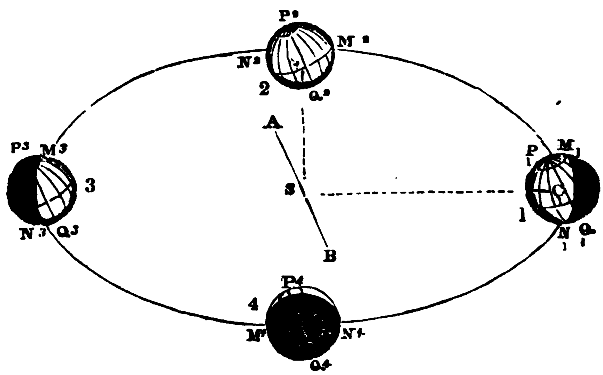
impulsive force, we suppose any other force to be applied to it precisely in the middle of its axis, or precisely through its centre of gravity, it is manifest that this force will have no tendency whatever to alter that parallelism, its effect on either side of the centre of the axis being the same. If, then, the attractive power of the sun, by which the earth is *deflected* from its rectilinear path, acted precisely as though it were applied to its centre only; then would it not in any way tend to alter that parallelism of the earth's axis, which would have resulted from the impulsive force alone. Now it does *very nearly* so act, and would do so *accurately*, were it not for the slightly spheroidical shape of the earth; and from that slight deviation of its form from a sphere, results the minute deflection of its axis, from east to west, which is called precession. By the operation of this force its pole is made to describe a circle in the heavens, describing annually $50''\cdot1$ of that circle, and thus completing its revolution in 25,868 years.

## XVIII.

### The Seasons.

The axis of the earth remaining throughout its annual motion thus parallel to itself, let us suppose the accompanying figure to represent four of its positions, determined as follows:—Let A B be drawn through the sun S, parallel to the directions of the earth's axis, in all its positions. Through A B draw a plane perpendicular to the plane of the earth's orbit, and let $C_1$ be the centre of the earth, when, by its revolution, it is brought into this plane. Through $C_1$ draw a plane $M_1$ $N_1$ perpendicular to S $C_1$, and this will be the boundary of light and darkness in that position of the earth. Draw $P_1$ $Q_1$ parallel to A B, and it will be the earth's axis. Take S $C_2$ perpendicular to S $C_1$, and let $C_2$ be the position of

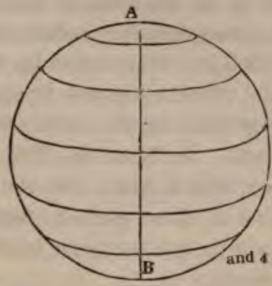
the earth's centre, when in its revolution it passes through the line $S\,C_2$,—draw the plane $M_2\,N_2$ perpendicular to $S\,C_2$,—then will it be the boundary of light and darkness; and if $P_2\,Q_2$ be drawn parallel to $A\,B$, it will be the earth's axis. 3 and 4

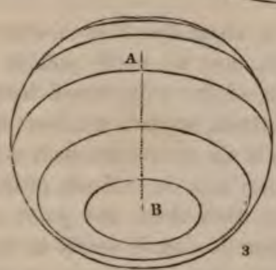



represent positions of the earth determined as the above, but on opposite sides of S. Now it is evident that in the positions 1 and 3, the earth's axis, $P_1\,Q_1$, $P_3\,Q_3$, is more inclined to the boundary of light and darkness, $M_1\,N_1$, $M_3\,N_3$, than in any of its other positions.* Also the line $S\,C_2$ being perpendicular to $S\,C_1$, and the plane $M_2\,N_2$ perpendicular to $S\,C_2$, it follows that $M_2\,N_2$ is parallel to the plane $A\,S\,C_1$; and, therefore, that $P_2\,Q_2$, which is parallel to $A\,B$, is in the plane $M_2\,N_2$; and the same is the case in the position 4 of the earth. All these relative positions of the earth's axis, and its boundary of light

* This will be readily understood if we imagine planes to be drawn through S, parallel to the boundary of light and darkness of the earth, in all its positions; these planes will manifestly be inclined to $A\,B$, precisely as the corresponding boundary plane is to the earth's axis. Also the greatest inclination will manifestly be that of the plane perpendicular to $C_1$.

and darkness, are shown on a larger scale in the accompanying figures.


In the positions 1 and 3, the earth's axis is inclined, at its greatest angle, to the boundary of light and darkness, and its poles are at their greatest distance from that boundary. Also, in the positions 2 and 4, the earth's axis is actually in the boundary of light and darkness. Thus, in the positions 2 and 4, every part of the earth is kept by its revolution as long in the shadow as in the light, and imbibes heat at every point of its surface, during precisely the same period of each revolution that it radiates or gives it out; and in the positions 1 and 3, there is the greatest inequality between the periods during which different parts of the earth receive the sun's rays, and are without them,—certain portions of it near one of its poles, being never carried by its revolution out of the enlightened hemisphere, and certain others about the opposite pole, being never carried out of that hemisphere

which is in the shadow, and every possible proportion of light and darkness existing between these extremes.

It is on the 21st of September in every year that the earth comes into the position shown in fig. 2, and on the 21st of March into the position fig. 4. These are called the autumnal and vernal *equinoxes*, because then the length of the day of every place on the earth's surface is equal to the length of the night. It is on the 21st of June and the 21st of December, that it comes into the positions 1 and 3,—and it is at the first of these periods that the action of the sun is most powerful in this northern hemisphere, and at the other that it is least.

In position 1, or about the 21st of June, a considerable portion of the earth, near the north pole, is never by its revolution carried out of the enlightened hemisphere, so that here there is a continual warmth and heat of the day. The apparent elevation of the pole of the heavens has been shown to equal the latitude; now the latitude of these polar regions approaches 90°, so that there the point about which the whole heavens appear to turn is nearly in the zenith. Thus the sun appears to the inhabitants of the arctic circle, about the middle of our summer, to describe, with the rest of the heavens, a circle round the horizon, at an elevation which increases continually from the 21st of March, until, on the 21st of June, it attains to about 23½°. On the contrary, about the region of the south pole, or, as it is termed, the antarctic region, there is then a perpetual night, the whole of the earth's surface, within 23½° of that pole, continuing as it revolves *without* the boundary of light and darkness.

In the middle of our winter, or on the 21st of December, matters are reversed, as shown in fig. 3. The enlightened hemisphere now includes the south pole, and the north is immersed. The inhabitants of the antarctic regions have now perpetual sunshine, and those of the arctic have perpetual night.

It is evident that, in the position 1, there is an excess of the length of the space through which each point of the northern hemisphere is carried in light, over that through which it is carried in darkness; that is, there is an excess of the length of the day over that of the night; whilst in the southern hemisphere there is the opposite proportion. Also, in the position 1, the sun's rays fall more perpendicularly on the northern hemisphere than in any other position. For both these reasons, then, because of the excess of the time of each place *receiving* heat over that during which it gives it out, and because of the less obliquity of its incidence, we have in this position of the earth *summer* in our northern hemisphere, whilst in the southern there is the *contrary* of all this, and consequently winter.

As the earth moves from position 1 to position 2, the excess of the day over the night diminishes, until at position 2, that is, on the 21st of September, it vanishes, and there is an equality, or it is the equinox. From 2 to 3, the night of the northern hemisphere continually gains on the day, and the difference is at 3, on the 21st of December, the greatest. From 3 to 4 it diminishes, and vanishes again at 4, which is the autumnal equinox.

## XIX.

### The Number of Revolutions of the Earth upon its Axis in a Year is one more than the Number of Days.

With regard to the annual motion of the earth, one of the first things which it is important to remark is,—that whilst it is revolving from one point in its orbit to the same point again, it does not make a complete number of revolutions. Thus, if at the instant when the meridian of any place is passing over a fixed star, the precise place of the earth in its orbit be ascertained, then, at the instant when it has returned to the same place in its orbit, that meridian will not be passing over

the same star as it would be if the earth in the interval had made a complete number of revolutions,—the revolution which it last commenced will remain uncompleted.

The number of complete revolutions which the earth will have made is 366; and of its 367th revolution it will have described that portion which it occupies $6^h\ 9'\ 9{\cdot}6''$ to describe. Now we usually say that there are 365 days and a quarter in a year, and each day is produced by a revolution of the earth upon its axis; how is it, then, that the number of revolutions is thus greater by one than the number of days? This will readily be understood by referring to the figure, p. 63. Let A, B, C represent successive positions of the earth in her orbit, S the sun, and A P, B P, C P, lines drawn from the centre of the earth to a fixed star, which are to be considered parallel to one another, because of the distance of the star. Suppose the meridian of any place on the earth's surface to pass over this star, and the sun at the same instant in the position A. In the position B, the star will appear at N, and the sun at K, and the meridian revolving in the direction K B N, will have to describe the angle N B K, after passing over the star, before it can pass over the sun; and when it passes over the star, it will have completed a certain number of revolutions *exactly*, from the time it left the position A; that is, it will have completed a certain number of sidereal days; and when it passes over the sun it will have completed a certain number of solar days, exactly: a certain number of revolutions or sidereal days, is, therefore, completed before the like number of solar days, or alternations of day and night, is completed.

Now, the angle, N B K, which the meridian has to describe after completing a certain number of sidereal days, before it completes the like number of solar days, is equal to the angle A S B, which the earth has, in the meantime, described about the sun; when, therefore, the earth has completed its revolution about the sun, or described 360°, the angle which the meridian has to describe, after completing a certain number of sidereal days, before it completes the same number of solar

days, is 360°; but this 360°, being a complete revolution, will take it just another sidereal day to describe, which will make the whole number of sidereal days one more than the whole number of solar days.

## XX.

### THE DIVISIONS OF TIME.

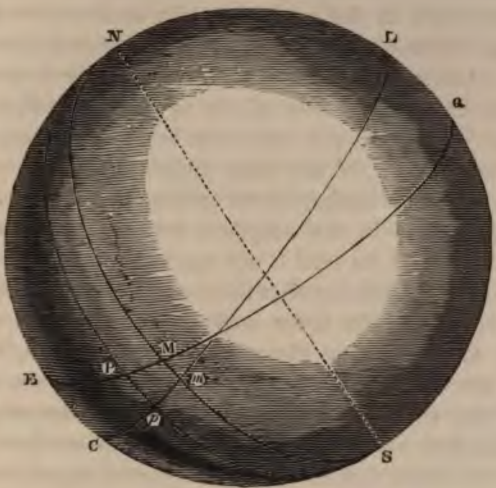
That division of time which is most obviously presented to us by the phenomena of the heavens, and which, as long as the world lasts, will continue to be the great practical division of time, is the alternation of a day and a night. This great division was established in the beginning of things, when God first divided the light from the darkness, and "the evening and the morning were the first day." But a very slight observation is sufficient to show us, that the length of the period of light, and the length of the period of darkness is perpetually varying,—that, for instance, the day of summer is longer than the day of winter, and that an opposite relation obtains with regard to the nights of these two seasons; but that the sum of these two periods, is, all the year round, and all the world over, nearly the same. This sum, which is nearly, and was at first imagined to be exactly uniform, was called a day. Thus we understand the full force of the expression, "the evening and the morning were the first day." The first measurement of the length of the time of light, and the length of the time of darkness, was no doubt made by observing the time between sunrisé and sunset, and between sunset and sunrise; and this method admits of considerable accuracy. It would soon, however, be found to be at once more convenient and more accurate to observe the interval between two apparent passages of the sun over the meridian, or two of its greatest successive elevations in the heavens.

Before instruments applicable to the exact admeasurement of angles came to be used, this was done by observing the interval between the times on two successive days when the length of the shadow of a vertical object was least.

This period is the true solar day. It is divided into 24 equal parts, called hours; and if these be counted from noon up to noon again, it is the astronomical day.

Now observations of so rough and uncertain a kind as those spoken of above, are yet sufficient to establish the fact, that this solar day is not constantly of the same length. This irregularity of the length of the solar, as compared with the sidereal day, arises principally out of two causes. The first is, that the sun's *apparent* path round the earth is not parallel to the apparent paths of the stars,—or, in other words, that the axis about which the sun apparently revolves round the earth every year (the axis of the ecliptic), does not coincide with the axis about which the heavens apparently revolve round it every day. The second cause is the continual variation of the motion of the earth in its elliptical orbit.

Let N C S L represent the sphere of the heavens, E Q the equinoctial, C L the ecliptic, N S the poles, *p* the place of the sun in the ecliptic, at the time when the celestial meridian N P S of any place is passing over it, *m* the place of the sun in the ecliptic on the *following* day. To pass over the sun on this following day, the meridian after completing its revolution into the position N P *p* S, must further revolve through the angle P N M into the position N M S; now the meridian revolves *uniformly;* if, therefore, the angle through which, in order to overtake the sun, it has to revolve every day, over and above a complete revolution, be the *same*, then will the length of time between its leaving the sun and returning to the sun again be the *same*,—or, in other words, the solar day will be always of the *same* length; but, on the contrary, if this angle be *not* always the same, the lengths of successive solar days will, for this cause, be different. Now, supposing the



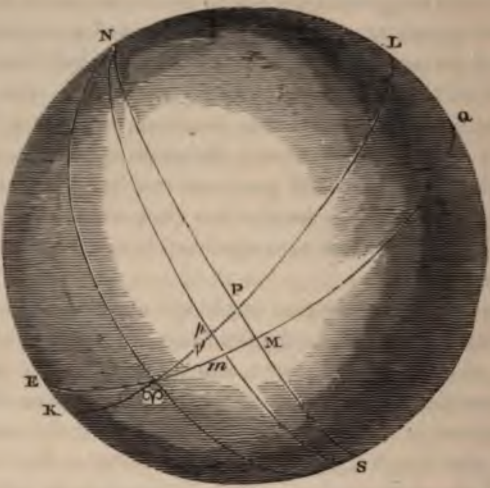

sun to move *uniformly in the ecliptic*, it is manifest that this angle cannot always be the same, because the ecliptic is *oblique* to the equator.

It is manifest that as the meridian revolves uniformly, it would carry a point fixed upon it *uniformly;* and if such a point were fixed upon it, half-way between the poles, it would carry it along the *equinoctial.* The meridian traverses, therefore, the equinoctial *uniformly*, and equal spaces on the equinoctial are revolved over, in equal times by the meridian, or correspond to equal angles described by the meridian; if, therefore, equal spaces on the ecliptic corresponded to equal spaces on the equinoctial,—that is, if taking distances *anywhere* on the ecliptic, each equal to one another, and to *p m*, the spaces P M on the equinoctial corresponding to them, were all of necessity equal to one another, then the corresponding angles P N M would all be equal; and if *p m* were the space described by the sun in the ecliptic every day in the year, then would every solar day be of the same length. But this

is not the case. If equal spaces, such as *p m*, be taken on different points of the ecliptic, it will be found, and it is manifest, that the spaces, such as P M, corresponding to these on the equinoctial are not equal,—the angles P N M corresponding to equal motions of the sun in the ecliptic are, therefore, *not* equal: and the solar day is not then, at all periods of the year, of the same length, and would not be, even if the sun's motion in the ecliptic were regular. But the sun's motion in the ecliptic is *not* regular, because the earth's motion in its orbit is not regular. Referring to the fig. in p. 63, we perceive that the angle N B S being equal to the angle A S B, if the latter angle, representing the earth's angular motion in any given time about the sun, be not always the same, then the angle N B S or the arc N K, representing the sun's apparent angular motion in the ecliptic in that time, will not always be the same. Now we know, and it will be *shown* hereafter, that the earth's angular motion about the sun is varied, because its distance from the sun varies continually. Thus, then, the irregular motion of the sun in the ecliptic is accounted for; it sometimes describes 57′ of the ecliptic in a day, and sometimes 61′; and from this cause arises a difference in the length of the solar day which may amount to 16″ of time. We have, then, two principal causes of irregularity, in the length of the solar day, and the true time of noon. 1st. The inequality of the angles through which the meridian must revolve on successive days to overtake the sun, caused by the obliquity of his path. 2ndly. The irregularity of his motion in his path, resulting from the elliptic form of the earth's orbit. If we imagine a sun to traverse the equinoctial instead of the ecliptic, with a continued *uniform* motion in the period of each year, or in 365·2422414 days, it will describe an arc of 59′ $8\frac{1}{3}$″ every day, through which arc the meridian will revolve in 3′ $56\frac{1}{2}$″ of sidereal time. If, therefore, P be the position of such a sun on one day, and M, at a distance 59′ $8\frac{1}{3}$″ from it, be its position on the next, then will the meridian N P S arrive at M,

3 $56\frac{1}{2}''$ after completing one entire revolution of the heavens. If, therefore, we take a pendulum clock, and so regulate the length of its pendulum, that its hour hand shall have completed $3'\ 56\frac{1}{2}''$ short of one entire revolution, in the period of one entire revolution of the meridian, as marked by two passages of the meridian over the same stars, then, $3'\ 56\frac{1}{2}''$ after this the meridian will pass over our imaginary sun, and, at the same instant, the hand of the clock will have completed its revolution. A clock thus regulated is said to be regulated to *mean* solar time.

Now let us suppose that our imaginary sun sets out from the point Aries, ♈, (see the figure on the next page,) at the instant of the vernal equinox, when the true sun also sets out from that point. Let us, moreover, suppose that the true sun moves in the ecliptic with an equal daily motion to that of the imaginary sun in the equinoctial. Let the dial plate of the clock be divided into 24 equal parts, and let the hand at that instant stand at 24. Also let the meridian N ♈ S be at that instant passing over the sun. Let $m$ be the position of the imaginary sun at the instant when the hand of the clock next points to 24, and the meridian is again passing over the imaginary sun. Since the angle ♈ $m\ p$ is a right angle, ♈ $p$ is the hypothenuse of a right-angled triangle, and is therefore greater than ♈ $m$. The true sun having, therefore, described in the ecliptic a space equal to that of the imaginary sun in the equinoctial, will be at some point $p'$ in ♈ $p$ such that ♈ $p' =$ ♈ $m$. Thus, then, when the meridian passes over $m$, it will, first, have passed over $p'$, or it will have passed over the true sun before it passes over the imaginary sun, or before the hand of the clock again shows 24 hours. Thus, about the equinox the time of *true* noon precedes the time of *mean* noon. For some weeks the time by which the *true* thus precedes the *mean* noon will continue to increase, until it has attained an interval of $10'\ 3{\cdot}9''$; it will then continually diminish until at the solstice it vanishes; for it is manifest




that there, the corresponding arcs of the ecliptic and equinoctial are equal; so that, supposing, as we have done, that the true and mean sun move each with the same uniform velocity, the meridian will pass over them both at the same time. True and mean noon coincide therefore at the solstices. After the solstice is passed, mean noon will begin to precede true noon, and the interval will again increase up to a certain point between this solstice and the following equinox; having then attained its maximum, it will begin to diminish, until at the equinox it vanishes, and mean and true noon again coincide. In passing on further to the next solstice, the time of true will begin to precede that of mean noon, and the same changes will be gone through as in the preceding half of the ecliptic, until both suns again come together, and both noons coincide in the point Aries ♈, whence they set out. Thus, then, on the supposition which we have made, that the sun moves *uniformly* in the ecliptic, it appears that the time of true and mean noon will alter-

nately precede one another, and that four times a year the interval between them will attain a maximum value.*

The sun does not, however, move uniformly in the ecliptic, by reason of the ellipticity of the orbit of the earth; and moreover, the velocity of his apparent motion is dependent, not upon his position with respect to the solstitial or equinoctial points, but upon the position of the earth with respect to the principal points of her orbit about him, her aphelion and perihelion, the nearest and most distant points. Thus, then, the amount of the deviation of the motion of the sun, at any point of the ecliptic, from his mean motion is dependent on the position of the perihelion of the earth's orbit in the ecliptic; moreover, this position is varying from year to year. Here, then, is another and most important cause of the variation of the time of true from that of mean noon, by reason of which cause alone it may be calculated that at certain periods of the year the time of true noon would differ from that of mean noon by about 8′ 20″ of time.

It has been before stated that, by reason of the obliquity of the ecliptic alone, the times of true and mean noon might be made to differ 10′ 3·9″ of time. If, then, the time of greatest variation from the one cause coincided with the time when the greatest variation takes place by reason of the other cause, then both thus conspiring, the whole variation of the time of true from that of mean noon would be not less than 18′ 23·9″. But this is not the case,—and the maximum interval between the time of noon, as shown by a good clock keeping mean time, and the true time of the sun's passing the meridian, never exceeds 16′ 17″ of time. Moreover, by reason of the irregularity introduced by the elliptic motion of the earth, the coincidence of the true and mean noon at the equinoxes and solstices is destroyed, and true noon is shown by the clock, not at the periods of the equinoxes and

* This maximum value will be attained when the sun is 46° 14′ from either equinox, and it may amount to 10′ 3·9″ of time.

solstices, but at the following periods,—the 15th of April, the 15th of June, 1st September, 24th December. The sun gains upon the clock between the two first of these periods, loses during the second, and gains again during the third. It is *behind* the clock by its greatest interval of 14′ 37″ on the 11th of February, and before it by its greatest interval of 16′ 17″ on the 3rd of November.

## XXI.

### Sidereal Time, Mean Solar Time, True Solar Time.

There are three methods of measuring time, commonly in use among astronomers.

1. It is measured by *sidereal* time, which is regular, being governed by the regular revolutions of the earth upon its axis, as shown by successive returns of the meridian to the same star.

2. It is measured by *mean* solar time, the nature of which has been sufficiently explained in the preceding pages, and the method of regulating an astronomical clock, so as to show that time (see page 87); this time, like sidereal time, is *uniform*, being dependent upon the period required by the earth, to make one complete revolution in her orbit.

3. Solar, or *true* time, as it is called, which is measured by the time between two successive noons, or actual passages of the meridian of any place over the sun; and that time not being the same at all seasons of the year, it follows that solar time is *irregular*, and that the solar hour, which is the 24th part of the solar day, has not exactly the same length on any two successive days.

The difference between true and mean solar time, explained in the preceding pages, is called the equation of time. Clocks, called equation clocks, have been so constructed, that whilst one of their hands shows on the dial-plate mean time, the other points to true time. The mechanism of a

clock, whose hand is to follow the irregular course of the sun, through each quarter of the year, is, however, so complicated, that little dependence can be placed upon it.

The sidereal day, which, like the solar, is divided into twenty-four hours, commences at the instant when the meridian, at the place of observation, passes over the equinoctial point Aries, and terminates when it returns to that point.

Thus the time of the sidereal day, when the meridian passes over any particular star, is the time which it takes to revolve from the equinoctial point Aries to that star; and since it revolves regularly through 15° in every sidereal hour,* it is manifest that, allowing at the rate 15° for each sidereal hour shown by the clock, (or, as it is called, converting the time into degrees,) we may ascertain at once the right ascension of the star,—which is no other than the number of such degrees intervening between it and the point Aries,—by observing the sidereal time when the meridian passes over it.

Since the right ascensions of all the principal stars have been accurately ascertained, by observing the sidereal time shown by the clock when the meridian passes over any such star, we may conversely ascertain whether the clock be right or not; and it is thus that astronomical clocks are regulated.

Solar time is found by observing the time of two successive passages of the sun over the meridian, and dividing the interval into 24 hours. It is the time shown also by a well-constructed sun-dial.

Mean time is found by observing the *true* time, and allowing according to the table of equation of time,† for its difference from true time. Thus, to determine the mean time of noon, we should *observe by our clock* the true time

* This is evident from the fact that it completes its revolution of 360° in 24 sidereal hours.

† The equation of time for every day in the year is usually to be found in almanacs.

of noon, or the exact time of the meridian passing over the centre of the sun. If then we deduct from this, or add to it, the equation of time for the noon of that day, the result will bring us to mean noon.

There is yet another, and practically a better method. If a clock be set to true mean time, the stars will every day complete an apparent revolution,—that is, the meridian itself will complete a *real* revolution,—precisely 3′ 55·9″ before the hour-hand has completed its revolution of 24 hours on the dial. Observe, then, two successive transits of a star; at the first set the hour-hand at 12, and regulate it so that at the second it shall show 3′ 55·9″ short of 12. It will then be regulated so as to show mean time. It only remains to *set* it at the mean noon, as explained in the preceding page.

## XXVIII.

### The Elliptical Form of the Earth's Orbit.

The earth revolves continually upon an axis within itself, and continually in an orbit about the sun. Hence result the alternations of day and night, the apparent motion of the sun among the stars, the difference of the duration of the *solar* from that of the *sidereal* day, and the different times of the rising of the same fixed stars. The axis about which the rotatory motion of the earth takes place remains always parallel to the same line in space; and hence result the phenomena of the seasons. But all these phenomena will be equally well accounted for by a revolution of the earth round the sun, in whatever orbit that revolution may take place,—and no inquiry which we have hitherto entered upon indicates with any certainty what is the real form of the earth's orbit. Provided the earth go completely round the sun in the space of a year, it matters not, so far as the facts which have hitherto been stated are concerned, whether

the motion of its centre be in a circle, in an ellipse, or in a spiral,—or in fact, whether it be in a square or an oblong.

We are now about to indicate the means by which the real form of the earth's orbit is ascertained, the nature and law of its motion in that orbit, and the actual dimensions of the orbit. It will then be explained how the apparent motion of the sun, the duration of the seasons, and the length of the year, are modified by these facts.

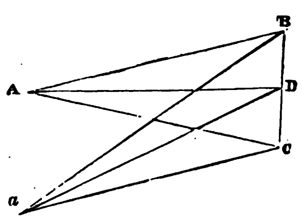
First, then, as to the form of the earth's orbit. It is not a circle, for then the sun would at all times of the year appear of the same size to us. We judge of the dimensions of objects by the angles which lines, drawn from the extremities of them, subtend at the eye. The conclusions we thus draw, we modify, however, by that which we know of the distance of the objects. Thus two objects, A B and C D, may subtend the same angle, C E D, at the eye, and yet we may be con-


scious that the yare of different dimensions, because we are conscious that they are at different distances. But if we were *not* conscious, and had no means of judging of any *difference of distance*, this would not be the case, and we should judge them to be of the *same* size. In like manner, if the two objects A B and C D were really of the same size, and we were unconscious of their difference of distance, since they would subtend different angles, we should judge them to be of different sizes; and thus the *same* object brought without our perceiving it to different distances would appear of different dimensions.

Rays of light come to us in straight lines. If, therefore, an instrument having two arms, which can be made to include any given angle between them, be placed so that its

angle being at the eye of the observer, one of these arms is in the direction of a ray coming from one point of the edge of the sun's disk, and the other in the direction of a ray coming from a point on the edge diametrically opposite to this, then these two arms of the instrument will include between them precisely the same angle which two lines drawn from opposite points of the sun, or opposite extremities of one of its diameters, to the eye, include. Two such lines, A B and A C, (see the next figure,) will form, together with the sun's diameter B C, a triangle, of which the angle, measured by the instrument, will be the vertical angle B A C, and the sun's diameter the base. Now the sun's actual diameter, the base of this triangle, must be supposed to remain always the same; and if the earth moved in a *circle* of which the sun was the centre, the two sides A B and A C of the triangle would always remain the same whenever the observation was made, and therefore the vertical angle B A C would always remain the same; that is, the sun's apparent diameter, as measured by the instrument which has been described, would always remain the same. Now it does *not*;—the earth's motion is, therefore, not in a circle whose centre is the sun.

The sun's apparent diameter on the 31st of December, 1828,* was 32′ 35·6″, or 32·5933′; and on the 2nd of July, 1829, it was 31′ 31″ or 31·5167′.† Now let A and *a* represent the positions of the eye of the observer on those two days. It then follows, by the rules of trigonometry, that since B A C and B *a* C are very small, B C may be considered as the arc of a circle, and that

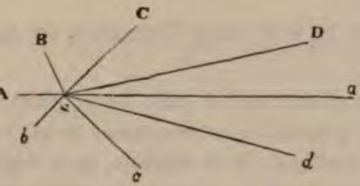



$$B A : B a :: \angle B a C : B A C$$
$$:: 31{\cdot}5167 : 32{\cdot}5933;$$
$$:: 1000 : 1034.$$

* At $2^h$ 31′ 15″ P M.

† At $5^h$ 45′ 41″ A.M.

Thus, if we suppose the whole distance to the sun on the 31st of December to have been divided into 1000 equal parts, on the 2nd of July its distance will have been increased by 34 of those parts. Now, between these two periods, it will be found that the sun has apparently moved through about 180 degrees of the heavens; or, in other words, that the earth has described 180 degrees about the sun: so that a line, D A, drawn from the centre of the sun to the earth on the 31st of December, and one, D *a*, drawn to it on the 2nd of July, make with one another an angle of 180°, or are in the same right line. Suppose A *a* in the accompanying figure to represent this line; take A S so as to contain 1000 equal parts, and *a* S 1034 of these parts; then, A S,



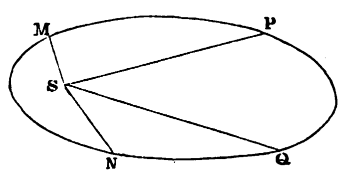

and *a* will represent the relative positions of the earth and sun at these dates. Knowing that the earth was in the position A on the 31st of December, we can tell what angle a line drawn from it to the sun in its position B at any other period, say the 1st of February, makes with S A; that is, we can find the angle A S B; in point of fact, this angle is the number of degrees measured upon the ecliptic between the sun's positions on those two days. Observing also the sun's apparent diameter, we can compare its distance on the 1st of February with that on the 31st of December; thus, taking A S as before to contain 1000 parts, we can find how many of these parts are contained by B S. Thus then we shall have determined the relative positions, A and B, of the earth in respect to the sun on the 31st of December and the 1st of February,—and we may proceed similarly to ascertain the

positions, C D, &c., of the earth in respect to the sun at the commencement of each month in the year. Of these distances we shall thus discover this remarkable property, (one of the laws of Kepler,) that they all lie in the *circumference of a figure called an ellipse;* of which curve the characteristic property is this, that if from two given points within it, called its foci, there be drawn two lines to any point in its circumference or periphery, the *sum* of these two lines will be the same wherever that point may be situated. Of the ellipse in question the sun will be found to occupy one of the foci.

## XXII.

### The Law of the Equality of Areas.

The form of the earth's orbit being thus ascertained to be an ellipse, a question at once arises as to the nature of its motion in that ellipse; is it *uniform*, as it might be supposed to be, if it revolved in a circle in which the sun was the centre? or is it in any way modified by the eccentricity of its orbit? The motion of the earth is *not* uniform; for if it were, the angles which it describes, in equal times, in different parts of its orbit, would be inversely as its distances at those times. Thus, if the earth, when at its least distance




from the sun, S, or in its perihelion, described in a day an arc M N, equal to that P Q, which it described in a day when

at its greatest distance, or its aphelion, then the angle P S Q would be to the angle M S N, in the ratio of M S to S P.

Now it is ascertained by observation, that when it is in its aphelion, the earth moves in its orbit (that is, the sun moves in the ecliptic) through an angle of 57·192′ in 24 hours, and that in its perihelion it moves through 61·165′ in that time; also its distance in aphelion we have shown to be to its distance in perihelion as 1034 to 1000; it follows, then, that if the earth's movement in its orbit were uniform, the ratio of 57·192′ to 61·165′, or of 1000 to 1069, should equal that of 1000 to 1034,—which it does not. It follows, therefore, that the earth's motion in its orbit is *not* uniform. But what law governs it? what relation exists between the angle it describes in a given time, and the distance at which it describes it?

Between the ratios we have just been stating there exists this remarkable relation. The distances are inversely as 1000 to 1034; and the angles as 1000 to 1069. Now if the first ratio is squared, it will become that of 1,000,000 : 1,069,156; and dividing both terms of it by 1000, it becomes 1000 : 1069, omitting the small fraction $\frac{156}{1000}$ in the last term. Now this ratio 1000 : 1069 is precisely that of the angles. The ratio of the angles is therefore equal to that of the squares of the distances taken inversely. Or, in other words, the angles described, in the same time, in aphelion and perihelion are inversely as the squares of the distances at which they are described. Whence it follows, that if the angle described in aphelion be multiplied by the square of its distance, the product shall equal the angle described in perihelion multiplied by the square of its distance.

Now this law does not only obtain with regard to the motion of the earth in aphelion and perihelion, but in every other position of its orbit. If the angle described in a day, for instance, in any part of its orbit, be multiplied by the square of its distance, the product shall equal the angle

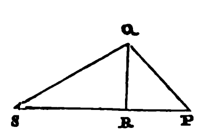
described in a day in any other part of its orbit, multiplied by the square of its distance on that day.

In the following table* will be found the angles observed to be described by the earth on the first days of the successive months of the year: and annexed to each is its distance on that day from the sun, in terms of the mean distance, which is taken as 10.

| | Angle. | | Dist. | | Angle. | | Dist. |
|---|---|---|---|---|---|---|---|
| Jan. . . . | 61′ | 10″ | . 9·830 | July . . . | 57′ | 13″ | . 10·168 |
| Feb. . . . | 60 | 51 | . 9·860 | Aug. . . . | 57 | 28 | . 10·144 |
| Mar. . . . | 60 | 5 | . 9·920 | Sept. . . . | 58 | 10 | . 10·082 |
| April. . . | 59 | 3 | . 10·066 | Oct. . . . | 59 | 7 | . 10·001 |
| May . . . | 58 | 6 | . 10·088 | Nov. . . . | 60 | 10 | . 9·910 |
| June . . . | 57 | 26 | . 10·146 | Dec. . . . | 60 | 56 | . 9·860 |

Now if the square of each of these distances be multiplied by the corresponding angle, the product will be found to be throughout the same. Generally, therefore, wherever the earth may be situated in its orbit, the angle it describes in a given time, a day for instance, being multiplied by the square of its distance, will always be the same quantity, viz., 5912·8.

This is a very remarkable law. It was discovered by Kepler, and is the observed fact on which the whole of Newton's physical theory of the universe is made to rest. Kepler did not, however, leave his law in this form in which it first occurred to him. Let us suppose P and Q to represent positions of the earth at the interval of a very small portion of time; an hour for instance, or a minute. Also let S be the sun. The line PQ being exceeding small, when compared with SP and SQ, may be considered a straight line, and SPQ a rectilineal triangle. Draw the perpendicular QR. This may be considered to be a portion of a




* This table is taken from Francœur's *Uranographie*, p. 64.

circle described from the centre S, at the distance S Q or S P. Q R will therefore equal the product of S P by the angle P S Q (S P $\times$ P S Q.) Now the area of the triangle P S Q is equal to one-half the product of S P by Q R ($\frac{1}{2}$ S P $\times$ Q R); therefore the area of this triangle is equal to half the product of S P by the product of S P and P S Q, or to $\frac{1}{2}$ S P$^2$ $\times$ P S Q. Thus, then, the small triangular area P S Q, swept over by the line S P, called the radius vector, in one minute of time, is equal to half the product of the angle P S Q by the square of the distance S P. And if this product be the same in every portion of the earth's orbit, it follows that the area swept over by the radius vector of the earth in every minute is the same, and therefore the area swept over in 60 minutes in one part of the orbit, is the same as that swept over in 60 minutes of any other portion of the orbit, and thus that the space or area swept over by the radius vector in one hour, in one day, or one week or month, in any one portion of the earth's orbit, is the same as the area swept over in any other. Now we have shown that the product of the angle described in a day by the square of the distance is the same everywhere. And precisely the same observations will prove the same fact in reference to the angle described in a minute. It follows, then, generally, that the area thus described by the earth in a given time in one portion of its orbit, is precisely the same as that described in the same time in any other portion. This is called the law of the equal description of areas. And it was in this form that it was promulgated by Kepler. We shall show, hereafter, that it results from this fact, that the deflection of the earth from the rectilinear path which it would otherwise have in space, is produced by a force acting always towards the sun, and not at different periods towards different points in space, or at the same time towards different centres. It points out, therefore, with certainty the sun as the controlling power in the earth's motion, distinguishing it in this respect from all the other material existences which people space, but establishing

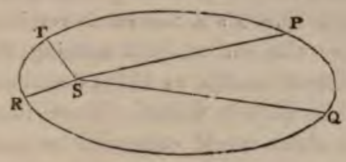
nothing as to the law by which its influence upon it is governed.

## XXIII.

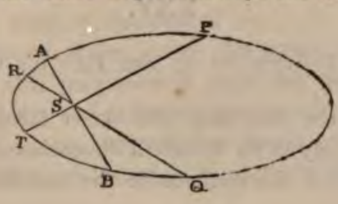
### The Equal Distribution of Heat to the Earth in Different Parts of its Orbit.

The earth is in perihelion, or at its least distance from the sun, in December; it would seem, therefore, that at this season our weather should be hotter than at any other. It is at its greatest distance in July; about that time we should therefore expect the coldest weather. We know the contrary of this to be the case. How is this to be accounted for? The variations of the seasons have been explained as dependant, not upon actual variations in the distance of the source of light and heat, but upon the relative obliquities of the directions in which the rays of light and heat are received, and on the relative lengths of the periods during which they are received; but unquestionably these causes, although in themselves they sufficiently explain our alternations of heat and cold, admit of being modified in their results by other causes, and especially by a variation in the distance of the sun. We might, for instance, be brought so much nearer to the sun in winter than in summer, as to make the temperature constant. And unquestionably, our actual variation of distance is such as would produce this effect in *some* degree, were it not for another cause tending in a great degree to modify this. The earth moves faster round the sun, or with a greater angular velocity, when it is nearer to the sun, than when it is more distant. So that in traversing a given distance off in space it has not so much time to receive heat when near the sun as when more distant. This will be evident from a mere inspection of the diagram. Let P Q and T R be portions of the earth's orbit described by it in the same time, say one month, the one

near its aphelion, and the other near its perihelion; then, by Kepler's law of the equal description of areas, the areas R S T




and P S Q are equal to one another; and the two distances S P and S Q being greater than S T and S R, it is evident that the angle P S Q must be less than the angle R S T in order to make up this equality. Now the law by which the light and heat of the sun are communicated to the same body when situated at different distances is this; if at any distance you multiply the quantity (anyhow measured) of light and heat which it receives in a given time by the square of its distance, the product will be the same as though you multiplied the quantity of light and heat which it receives in the same given time at any other distance by the square of that distance. This is commonly expressed by saying that quantities of light and heat are inversely as the squares of the distances. But we have shown that if we multiply the angle described in any given time by the square of the distance, that product will equal a similar product taken in any other part of the orbit. The quantity of heat received in any given time varies, then, according to precisely the same law that the angle described in that time varies,—the relation of both to the distance is the same. And thus the quantity of heat received by the earth in describing the same angle is always the same. Thus, if



P S and Q S be produced to T and R, since the vertical angles at S are equal, there is as much heat received by the earth in moving from Q to P, as in moving from R to T. Or drawing the straight line A S B, the earth receives precisely as much heat from the sun whilst describing the space A P B during the summer months, as whilst describing the portion B R A, which is its path in winter. Thus, that modification of the seasons which would otherwise be produced by our different distances from the sun is altogether got rid of, and the causes we have assigned for these phenomena exercise their full influence.

## XXIV.

### The Position of the Earth's Orbit in Space.

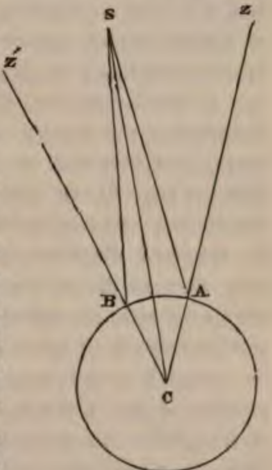
We have now described the form of the earth's orbit. Its position, too (which, not being a circle, but an oblong, is of importance), is easily known thus:—The earth came to its perihelion on the 31st of December, as was known from the fact of its diameter being then the greatest, also the sun appears always in the opposite quarter of the heavens to that occupied by the earth. Ascertaining, then, what is the opposite place of the sun in the ecliptic on the 31st of December, and measuring from this 180 degrees, we know the precise position of the earth at that time, and, therefore, of the perihelion. The opposite quarter of the heavens is the aphelion; and thus we know which way in space the length of the elliptic orbit lies, and of course which way its breadth lies.

## XXV.

### The Dimensions of the Earth's Orbit.

Knowing the form and position of the earth's orbit, it remains now only to fix its actual dimensions. The general method by which the distance of the sun from the earth is

found, the reader will readily understand. Let A and B be two places on the earth's surface, which are on the same meridian of longitude. And suppose that at the same instant two observers ascertain the angular distance of the sun from the zeniths Z and Z′ of these two places. These angular distances will be the angle Z A S and Z′ B S, which will therefore be known. Also the latitudes of the places of observation being known, the angle A C B, which is the sum, or difference of these latitudes, is known; and the dimensions of the earth being known, the radii C A and C B are known. Now having these quantities given, we can determine, by the rules of trigonometry, all the others which concern the quadrilateral figure A C B S; as will be evident to any one acquainted with that science. It may be, however, made plain to those who are not, as follows:—If two lines, C A and C B, be taken, inclined to one another at an angle, A C B, equal to the sum or difference of the latitudes, and as many equal parts be measured off from C A as there are miles in the corresponding radius of the earth, and as many from C B as in the radius corresponding to B; also, if at the points B and A, thus determined, lines A S and B S be drawn, inclined to A C and A B at angles equal to the observed zenith distances Z A S and Z′ B S, then the lines A S and B S will meet in some point, S, determined




by the conditions under which the figure has been constructed; and this point S will hold the same position in respect to A and B and C that the sun does in respect to the two places of observation and the earth's centre. If, then, we find how many of the equal parts used there are in S C,

we shall know the number of miles which the earth's centre is distant from the sun.

The method which has been described is one of the least artificial that can be conceived. In actual practice, the compass and rule would fail us for want of accuracy, and calculations thus made would not give even an approximation to the truth, by reason of the great length of S A and S B as compared with C A and C B. We must, therefore, have recourse to trigonometry, by a very simple operation of which we shall be enabled to determine S C, knowing C A, C B, B C A, Z′ B S and Z A S. It is thus ascertained that the mean distance of the sun is 23984 radii of the earth, or that S C is 23984 times A C. This result is confirmed by other and independent observations and calculations of a more complicated, and of a more accurate nature. We may, therefore, assume as a result, which cannot possibly be in error beyond certain known, and those comparatively very narrow limits, that the sun is distant from us 95 millions of miles. The greatest diameter of the earth's orbit is equal to twice its mean distance, or 47968 radii of the earth. Now it has been shown that the sun's distance from the two extremities of this orbit are in the ratio of 32593 to 31517; this being the ratio of its apparent diameters in aphelion and perihelion, we have only then to divide the number 47968 into parts, which are in the ratio of 32593 to 31517, and we obtain for the earth's distance in aphelion 24388 radii of the earth; and for its distance in perihelion 23580 radii. Knowing, thus, the position of one of the foci of the earth's orbit, and the length of its greater diameter, we can determine all its dimensions. Thus, then, the magnitude of the earth's orbit is completely known.

## XXVI.

### The Plane of the Earth's Orbit.—Celestial Longitude and Latitude.

In our reasonings hitherto, we have supposed the observer to occupy a position on the earth's surface, and everything presented to him under these circumstances has necessarily been presented under a complicated form, combining with its proper motion another *apparent* motion, arising from a continual change in the observer's point of view: to separate these two motions is a distinct operation of the mind, and one of considerable effort.

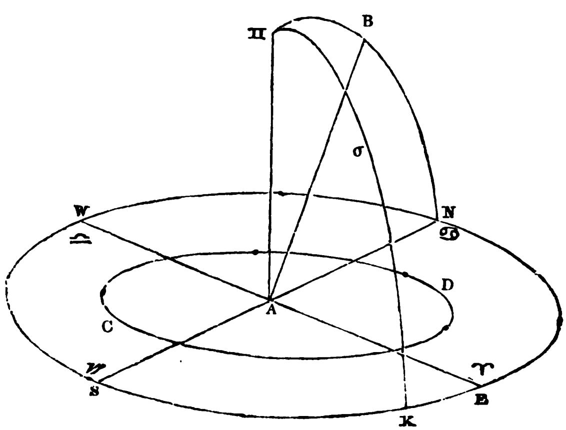
The mind may now, however, take up a new position in the universe, and in imagination move at will on the surface of a fixed invariable plane, that of the earth's orbit, which, when produced in the vault of the heavens, traces out there the ecliptic. Let a line be drawn perpendicular to this plane through the sun, and it will mark on the heavens a point called the pole of the ecliptic; great circles of the heavens drawn through this pole perpendicular to the ecliptic are called circles of celestial latitude, and the latitude of any point in the heavens, is the number of degrees between that point and the ecliptic, measured on one of these circles.

If a line be drawn through the sun parallel to the direction of the earth's axis, and through this line a plane perpendicular to the plane of the earth's orbit, this plane will intersect,—the heavens in a circle called the solstitial colure,—the line of the earth's orbit in the points which we have before shown to be those occupied by its centre at the solstices*—and the celestial ecliptic in two points called Cancer ♋ and Capricorn ♑, in which points of the heavens are the sun's apparent places at the times of the solstices. If from these points were measured off 90 degrees both ways on the ecliptic, we should determine two points in it called the equinoctial

* These are the northern and southern points of the earth's orbit.

points ♎, and ♈, where the sun appears at the equinoxes. The number of degrees from Aries ♈, eastward, of the point where the circle of latitude of any place in the heavens cuts the ecliptic, is called the *longitude* of that place of the heavens.

Thus, if N W E S be the intersection of the plane of the earth's orbit, C D with the sphere of the heavens, this line, N W E S, will be the *celestial ecliptic*, and if A Π be perpendicular to this plane, and intersect the sphere of the heavens in Π, Π will be the pole of the celestial ecliptic. If A B be parallel to the earth's axis, and the plane Π B N S be drawn through this line and A Π, it will be perpendicular to the plane of the ecliptic. The intersection, Π B N, of this plane with the sphere of the heavens, will be the solstitial colure, and S and N will be the solstices Capricorn ♑ and Cancer ♋, and the south and north points of the ecliptic; 90 degrees from these will be the points ♈ and ♎, of which the former is the eastern and the latter the western point of the ecliptic. The latitude of any point $\sigma$ of the heavens is the arc, $\sigma$ K, of a great circle, Π $\sigma$ K, of the heavens passing through $\sigma$ and through the pole Π, and its longitude the arc ♈ N W S K of the celestial ecliptic.



The sphere of the heavens which we are now describing is in reality a different one from that before spoken of; that sphere had its imaginary centre in the centre of the earth; this has for its centre the centre of the sun; so that the centre of its former sphere was in motion, and its motion was perpetually *round* the centre of this sphere. But it was shown that the radius of the circle in which this motion takes place is infinitely small as compared with the radius of the great sphere of the heavens; so that, so far as the appearance of objects on its surface was concerned, it might be considered to be at rest. So far as the appearance of these objects is concerned, it may therefore be supposed to coincide with the centre of that sphere of which we are now speaking. Considering, then, the centres and surfaces of these spheres to coincide, we shall have two sets of lines on the celestial sphere, the one having reference to the equinoctial, and the other to the ecliptic, and two poles, one being that of the former, and the other of the latter. The right ascension and declination of any heavenly body or point in the heavens is measured and fixed by means of the former set of lines, precisely as its longitude and latitude are by means of the latter.

## XXVII.

### The Earth's Path in Space is continually changing.

It is a source of great perplexity in astronomy, that none of those systems of lines which are imagined to be described in space, and none of those points to which are referred our admeasurements of the positions of bodies upon the celestial sphere, are in reality *fixed.*

To begin with the earth's orbit: it is found that by reason of the disturbing attraction of the other planets composing our system, the earth does not, year after year, describe the same path in space. If observations be made determining

the position of the line of the apsides, or the line joining the aphelion and perihelion of the orbit in which it is moving in one year, these observations being repeated the next, will show that it is then moving in an orbit, the line of whose apsides* differs in direction from the former by an angle of 11·8″ eastward. The longitude of the perihelion was, on the 1st of January, 1801, 99° 30′ 5″, and during the thirty-four intervening years it has increased thirty-four times 11·8″, so that now, if the position of the point ♈ from which it is measured had remained the same, it would be 99° 36′ 46·2″.

## XXVIII.

### The Sidereal Year.

The time after which the earth returns into the same position in space with respect to the sun, or after which the sun appears to return to the same point in the heavens, is called the Sidereal Year: its length is $365^d\ 6^h\ 9'\ 11{\cdot}5''$.

## XXIX.

### The Anomalistic Year.

The time intervening between two successive passages of the earth through an aphelion or perihelion, of its orbit, is called an Anomalistic Year: it is greater than the time it would require to bring the sun apparently to the same point of the heavens, by the time of describing 11·8″, by which distances the apsides alter their position annually; the length of the anomalistic year is therefore $365^d\ 6^h\ 13'\ 58{\cdot}8''$.

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* The perihelion and aphelion of a planet's orbit are called its apsides.

## XXX.

### The Precession of the Equinoxes.

Were the position of the earth's axis always *accurately* parallel to itself, the position of the plane A ♊ B N, fig. p. 106. would always be the same; and thus the positions of the points ♋ and ♑, and also ♈ and ♎, dependent upon this plane, would always be fixed; so that the longitude of any fixed point in the heavens, as for instance a star,—which longitude is the distance measured upon the ecliptic of that point from ♈—would always be the same. But the earth's axis is not always accurately parallel to itself; it varies continually its inclination, according to a law dependent upon the rotatory motion of the earth about its axis, and the attraction of the sun upon the spheroidical excess about its equator. This variation in the parallelism of the earth's axis, brings with it a change in the position of the line A B in the figure, and of the plane A ♊ N, and ultimately of the position of ♈, which point is thus made to move 50·1″ every year backwards, or in a direction opposite to that of the earth's motion. This annual regression of the equinoctial point ♈, by reason of which the earth is made to arrive at that point, every year, earlier than it otherwise would do by the time of describing 50·1″ of its orbit, is called the Precession of the Equinoxes.

It is manifest that the longitude of a star increases every year by the amount of this precession, not by reason of any motion of the star, but by reason of a falling backwards of the point from which it is measured.

## XXXI.

### The Tropical Year.

The earth does not return to its equinoxes, and therefore to the tropics, after the same period which it takes to come

back to the same point in space, but in a period less than this by the time of describing $50 \cdot 1''$ of longitude. The time of returning from equinox to equinox, or from tropic to tropic, is therefore shorter than the sidereal year by the time of describing $50 \cdot 1''$, and is called the TROPICAL YEAR; its length is $365^d\ 5^h\ 48'\ 51 \cdot 6''$.

## XXXII.

### THE MOON.

Like the sun, the moon has an apparent motion from west to east amongst the fixed stars. In tracing her path, however, we encounter none of those difficulties which beset the investigation of the ecliptic, or sun's path in the heavens. The stars are, many of them, visible by moonlight; and as these are fixed in the heavens, and their places known, we can tell accurately the position of the moon at any time, by measuring her angular distance from any two of these. Setting off these distances on the celestial globe, her exact place on it will be known, and this being done from day to day, her path will be traced out. Her motion is so exceedingly rapid amongst the stars, that she may almost be seen to move among them; describing somewhat more than half a degree every hour. She thus makes a complete circuit of the heavens in a mean or average period of $27^d\ 7^h\ 43'\ 4 \cdot 7''$, called a periodical lunar *month*.

## XXXIII.

### THE PHASES OF THE MOON.

During four or five days of each revolution, the moon is invisible; and she always becomes thus invisible when her position in the heavens is within an angular distance of about 30° on either side of the sun; she first appears under the form

of a slender crescent, or semicircle of light, about 30° above the western horizon at sunset; her angular points, or horns, are then turned towards the left of the spectator, her motion being eastward, at the rate of about 13° through the heavens in twenty-four hours. The sunset of the next evening finds her somewhere about 12° further from the sun, who has moved in that period about 1° in the same direction; thus her elevation above the western horizon at sunset is now about 42°; her crescent, from a mere line, of light now presents the appearance of a lune, as it is termed, of considerable breadth, and in four or five days more, when she has attained a distance of 90° from the sun, and passes the meridian at sunset, the space between her horns is filled up with light, and her disc has become a complete luminous semicircular area. She is then said to have completed her first quarter. As she still advances towards the east, this semicircle swells into a figure, whose edge is still a semicircle, but whose base is now an elliptic lune; she is then said to be *gibbous*, and in her second quarter; this quarter she terminates when her distance from the sun has increased to 180°, and when she rises about sunset. Her disc is now a complete circle, and she is said to be at her full. Still continuing her journey eastward, her full orb begins to contract on that side or limb, as it is termed, from which she is moving, until her distance from the sun is 270°, and she completes her third quarter, when she is again a semicircle, or half moon; and in her fourth or last quarter she wanes, until, as before, she becomes only a thread of light, and finally disappears when she has a second time approached the sun to within the distance of about 30°. When she is in the middle of that portion, 60°, of her orbit in describing which she is invisible, she has the same longitude as the sun; and the instant when this occurs is called the time of new moon. These different appearances of the moon are called her PHASES.

## XXXIV.

### Mountains and Cavities on the Moon's Surface.

Although certain portions of her disc are thus, to the naked eye, always, except at the full, obscured, yet may the whole disc at any time be distinguished by the aid of a telescope,—dark, indeed, but yet not so dark as the surrounding sky—by reason of the light reflected upon her from the earth, and called the earthshine. This obscured disc of the moon is most easily seen towards the time of new moon, and especially about the third day from it. As seen through a telescope, that edge of the moon by which it is waxing or waning presents always an exceedingly ragged appearance, and occasionally bright spots may be distinguished at a short distance from it, in the otherwise obscured part of the disc. The appearance of the disc itself, under the telescope, is exceedingly varied; it is covered with irregular markings, of which the light is dimmer than that of the rest, and which have the appearance of stains. Of these some are manifestly the shadows of mountains; in other places may be traced the appearance of cavities, commonly of circular forms, on the sides of which, lying towards the sun, are dark shadows, by measuring the widths of which, the depths of these cavities may be estimated. The same method of measuring the width of the shadow serves to ascertain the heights of the lunar mountains; these are, some of them, about $1\frac{3}{4}$ miles in height, and the depth of the deepest cavities may be about the same.

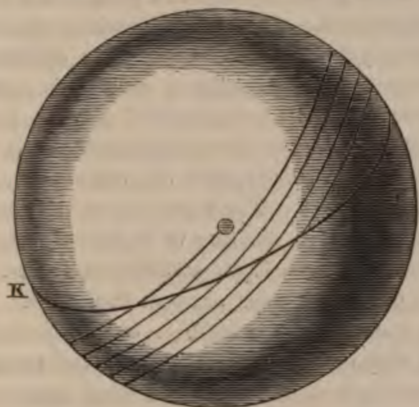
## XXXV.

### The Moon's apparent Path in the Heavens.

If the path of the moon be accurately observed and traced during any one revolution on the celestial sphere, it

will be observed—First, that the line along which she moves through the heavens, and among the stars, is not very far removed from the path of the sun, but that it does not accurately coincide with it; being, in point of fact, inclined to the ecliptic or sun's path, at an angle of 5° 8′ 48″.

Secondly, that she does not return, after each revolution, exactly to the same point of the heavens from which she set out, so that no two successive revolutions are made through exactly the same path in the sky. She does not, in fact, describe a great circle of the celestial sphere, but a continuous spiral, which at each revolution intersects itself, and which, at every intersection with the ecliptic, is inclined at the same angle of 5° 8′ 48″ to it. The points of this spiral orbit




where the moon intersects the ecliptic, are called her NODES; and when she thus passes from the southern to the northern side of the ecliptic, she is said to be in her *ascending* node; when from the northern to the southern, in the *descending* node. Were her apparent orbit a great circle of the sphere, these nodes would be exactly 180° from one another, but by reason of the spiral form of her apparent orbit, whence results a continual deflection of her path from the plane

of the great circle on which she first set out, she is brought to cut the ecliptic *before* she has completed her circuit of 180°; and, setting out again from this node, she again comes to the ecliptic before she has travelled 180°. Thus, then, leaving her ascending node, or ascending north of the ecliptic, to her greatest distance from it, then passing beneath the ecliptic and to her greatest depth beneath it, and ascending again, she finally crosses the ecliptic at an ascending node a second time before she has completed 360°; or the ascending node has, during this revolution, fallen back, as it is termed, upon the ecliptic. Now this occurs at every revolution; there is, therefore, a continual regression of the moon's nodes upon the ecliptic—precisely analogous to that of the equinoctial points in the sun's path, called the precession of the equinoxes. Although these phenomena have thus a resemblance, yet they arise out of very different causes, and the amount of the regression of the moon's nodes is very different from that of the equinoctial points. The annual amount of the regression of the equinoxes on the ecliptic is 50·1″, one degree in 71·8563 years, or a complete circuit of the ecliptic in 25868 years. The regression of the moon's nodes upon the ecliptic is at the rate of 3′ 10·64″ a-day, or one degree in about nineteen days; 19·3286° in a year; and 360° in 6798·279 mean solar days, or about 18·6 years. When the nodes have thus completed 360°, or one revolution through the ecliptic, they commence another, and the moon retraces the spiral path in the heavens which she had commenced 18·6, or nearly nineteen, years before. This path of the moon, described in 18·6 years, if traced upon the celestial sphere, would be found almost to cover, with a series of intersecting lines, a belt or zone of somewhat more than 10° in breadth, having the ecliptic in its centre. In the period of 18·6 years, the moon, then, passes at least once over every point in this belt,* and of the stars which lie in it, which, as we shall

* The width of the moon's disc is here taken into account.

shortly see, are all of them infinitely more remote than the moon, it occults or hides from our view, at some time or another, every one. And the sun, too, which moves (or whose appearance in the heavens is the same as though it moved,) sluggishly along the centre of this belt, must evidently once, and in reality more than once, have the centre of the moon pass nearly over the centre of his disc, and there must be very many positions of the moon in which her disc must *partially* intervene between us and that of the sun. It is manifest, that knowing the exact motion of the centre of the moon in her orbit, and knowing the exact motion of the centre of the sun in the ecliptic, we can tell when their discs will interfere with one another; for we can tell when the distance of their centresis less than the sum of their radii; whenever this is the case, the limb of the moon must be superposed. It is under these circumstances that a solar eclipse takes place, and it is thus that the time of a solar eclipse is calculated.

It is manifest that, since the moon describes again the same path always after 18·6 years, passing over any star, she will return after 18·6 years, and pass over or occult that star again, as she did before: in respect, then, to the occultations of fixed stars, 18·6 years may be considered as the cycle of the moon. If the sun remained stationary in the heavens as do the fixed stars, after the moon had in any way eclipsed it, it would return and eclipse it again, precisely in the same way, and to the same degree, when this cycle of 18·6 years had expired. But the sun is *not* fixed in the heavens; he moves about one degree daily, and describes 360° in one mean solar year. He will not, then, like the moon, in 18·6 years have arrived again at the place in his orbit from which he set out. But, nevertheless, by a very remarkable coincidence, at the *end* of the nineteenth year, that is, $\frac{4}{10}$ of a year only after the expiration of the cycle,—when the sun is, of course, in the same place in the heavens as he occupied nineteen years before, and the moon is revolving in a circle

or turn of her spiral path (see the preceding figure) which is but a short distance from that in which she was revolving $\frac{4}{10}$ of a year before at the expiration of her cycle, and, therefore, very little different from that in which she was revolving at its commencement, nineteen years before, her longitude will be precisely the same as it was at the commencement of the cycle. Thus describing nearly the same path in the heavens, and having the same longitude, or being at the same point in that path, she must occupy very nearly the exact place in the heavens which she did nineteen years before; the sun, moreover, occupies the same place. *Whatever relative positions they had then, they must, therefore, have now; and if there was an eclipse then, the same eclipse must occur now.*

It is easy to ascertain that the longitude of the moon will be the same nineteen years hence as it is now. The moon will return once into the same position with respect to the sun in longitude that it has at the present instant, that is, it will complete what is called one synodic revolution* in 29·5305886 days. And it will have returned into the same position with respect to the sun 235 times, after 235 such synodic revolutions, or after 235 times 29·5305886, that is, 6939·6 days. Now this period of days is precisely nineteen tropical years; but, after this period, the sun will have returned nineteen times to the same place in the ecliptic. The sun is, therefore, in the same place, and there is the same difference of longitude between it and the moon, as nineteen years before. And moreover (and this is the chief point), the moon is describing very nearly the same turn or circle

* A *synodic* revolution of the moon is the time of its return from the *sun* to the sun again, or from any position (in longitude) in respect to the *sun* to the same position in respect to the *sun* again. A sidereal revolution of the moon is its time of revolution from a particular *star*, or any position in respect to it, to the same *star* again, or the same position in respect to it. These times differ because the sun moves (apparently) in the interval, and the star does not.

of her apparent orbit, so that her latitude at that time is very nearly the same as nineteen years before, and, therefore,—her latitude and the difference of her longitude and that of the sun being the same,—the distance of her centre from his is the same.

The discovery of this cycle, in which all the appearances of the moon in respect to the sun return in the same places in the heavens, and at the same dates of the year, including even the eclipses, is attributed to Metho; it was adopted by the Athenians, 433 years B. C., to regulate their calendar, the dates and festivals of which were made partly to depend upon the appearances of the moon. They engraved the number, and the process of the computation of it, in letters of gold on the temple of Minerva, and thus it was that the number which marks the position of any year in the lunar cycle of nineteen years, came to be called the Golden Number.

## XXXVI.

### The Moon's Real Path in the Heavens.

Such are the appearances of the moon in the heavens; appearances which any one may verify by direct observation. Now it is the object of that branch of astronomy called Plane Astronomy, of which we are now treating, from the apparent motions of the heavenly bodies to educe their true motions. What, then, is the *real* motion of the moon? She *appears* to revolve round the earth in a path very nearly coinciding with the ecliptic; but the sun *appears* also to revolve round the earth in the ecliptic. There is every possible analogy between the two motions; both are from the west eastward, both partake in the apparent diurnal motion of the heavens westward; the only apparent difference lies in this, that the one makes more than twelve revolutions while the other makes one revolution. Now the sun does not, as we have

shown, revolve round the earth as he seems to do; on the contrary, it is the earth which revolves round the sun. What shall we say, then, of the moon, whose apparent motions have so striking an analogy to those of the sun? Does the earth revolve round the moon, too, as well as the sun? In the first place we may remark, *that it is impossible the earth should revolve round two centres in two different periods, both being at rest.* Let us, however, consider if the analogy holds throughout. In the first place, by reason of the *quicker* revolution of the moon, it is a probable hypothesis that she *has not so far to travel* to complete that revolution as the sun (or rather the earth) has, and, therefore, that her distance is not so great. Now, by observations precisely analogous to those which we before explained for determining the distance of the sun, it is ascertained that this is really the case. The mean distance of the moon is 60·2379 radii of the earth, or only one four-hundredth part of that of the sun, or 238361 miles, and *her whole orbit* might be nearly *twice included* within the mass of the sun. Now knowing the distance of the moon, and knowing, by observation, her *apparent* diameter, that is, the angle which her real diameter makes to an observer at the earth, we know, by solution of an isosceles triangle (of which we know the sides and vertical angle), what her *real* diameter is. And from this diameter we can find what is her surface, and her bulk or volume. The mean distance of the moon from the earth's centre is 60·2379 radii of the earth, and her mean apparent diameter is $31' \, 7''$, whence it may be calculated that her real diameter is about $\frac{3}{11}$ of the diameter of the earth, her surface $\frac{3}{40}$, and her volume $\frac{1}{49}$. Now the *apparent* revolution of the moon round the earth can only be accounted for in two ways,—either by supposing this apparent motion to be a real motion, or by supposing the apparent motion of the moon round the earth *not* to be *real*, but to arise from a real motion of the earth round the moon. This last hypothesis is rendered exceedingly improbable, by the exceeding smallness of the moon in comparison

to the earth,—it is an exceedingly improbable supposition that the earth should revolve continually round a body only $\frac{1}{49}$ of its own bulk,—and this improbability becomes an actual impossibility when we take into account the fact, which has elsewhere been proved, of the annual revolution of the earth about the sun. It is *impossible* that the earth should revolve every (lunar) month about the moon, and revolve at the same time annually with it about the sun, and yet the sun present those appearances which we know it to present; its motion in the ecliptic would at once lose all its regularity: instead of advancing continually among the signs, it would at one time move forward with a velocity of 14° daily through the sky, and at another retrograde 12° daily: in short, it is useless to enter further into the discussion,—the hypothesis is manifestly impossible; and admitting the earth to revolve round the sun in the interval of each solar year, we are compelled to admit that the moon accompanies it in this, its annual revolution, at the same time continually revolving round it in the period of each lunar month.

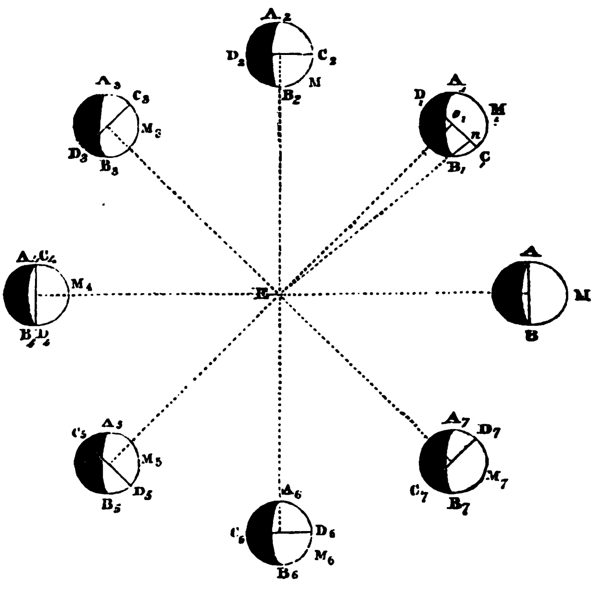
## XXXVII.

### The Phases of the Moon explained.

The most remarkable phenomenon in the appearance of the moon, is that series of changes which takes place during each of its synodical revolutions in the form of its disc, and which we have described as the variation of its phases. We are now in a condition to explain these completely.

So great is the distance of the sun in comparison with the radius of the moon's orbit (400 times greater), and so great is its comparative bulk, that the rays of that luminary which fall upon different parts of the orbit may be considered to be all parallel to one another. That portion of the sphere of the moon which is turned towards the rays of the sun is,

in all its positions, enlightened, whilst the opposite portion or hemisphere is in darkness. Now if this hemisphere of the moon which is always enlightened, were also always turned towards the earth, the moon would always be visible; she would always appear full. This, however, is far from being the case; the enlightened hemisphere is, in all the positions of the moon, that turned *towards* the sun, and, therefore, there are certain of these positions in which it is turned altogether *from* the earth; certain others in which it is *partially* turned from it; and only one position in which it is *altogether* turned towards the earth. Thus, then, there are certain positions in which we see none of the moon's enlightened disc, *i. e.*, we do not see the moon at all, certain others in which we see only part of it, and only one position in which we see the whole disc.



The orbit of the moon is but slightly inclined (at an angle of 5° 9′) to the plane of the ecliptic, that is, to the plane in which the earth revolves about the sun. Hence, therefore, there are certain positions of the moon in her orbit in which she lies between us and the sun, and certain others in which we lie between her and the sun. Let $A$, $A_1$, $A_2$, $A_3$, represent different of these positions of the moon in her orbit, and draw planes $A\,B$, $A_1$, $B_1$, $A_2$, $B_2$, &c., through her centre, perpendicular to the direction of the sun's rays falling upon her in each of these positions. Then it is manifest that $A\,M\,B$, $A_1\,M_1\,B_1$, $A_2\,M_2\,B_2$, &c., will be the enlightened hemispheres of the moon's surface, and that the opposite hemispheres will be dark; also, that in the position $M$ no part of this enlightened hemisphere can be seen from the earth; that in the position $M_1$, only the portion $B_1\,C_1$ can be seen; in the position $M_2$ only $B_2\,C_2$; in the position $M_3$, only $B_3\,C_3$, &c. If the moon were near enough to us, we should thus see at different times portions of her surface, which would have the appearance of different sections of a spherical surface. But by reason of the great distance of the moon, we cannot distinguish that variety of shading by which the portion of the enlightened surface which we see may be ascertained to be curved; and it appears to us to be perfectly flat. The *width* of this perfectly flat portion which we thus see is in the position $M_1$; the distance between two lines drawn, one from $E$ to the boundary $B_1$, of the enlightened part, and the other to the boundary $C_1$. And this distance $C_1\,n$ is what is called the versed sign of the angle $B_1\,O_1\,C_1$. Now this angle $B_1\,O_1\,C_1$, is easily seen to be equal to the angle $O_1\,E\,M$; that is, it is equal to the angular distance of the moon from the sun; or, as it is termed, the moon's elongation. The width of the moon's disc is, therefore, always equal the versed sine of the elongation.

Now the versed sine of an arc increases as the arc increases up to 180°, and then diminishes in the same order and degree; thus, then, the width of the apparent disc of the

moon increases until her elongation is 180°, and then diminishes in the same order until it is 360°, or until she returns to conjunction with the sun again. It will be perceived that she wanes always in respect to that portion of her disc which lies towards the direction *from* which she is moving. Now she moves from west to east; her horns lie, therefore, always towards the west when she is waning. In this hemisphere, when we look at the sun and moon, we look always towards the south, and the east is then to the left of us; thus the moon's horns lie always towards the right when she is waning, and in the contrary direction when she is waxing or increasing. The plane which divides the enlightened from the unenlightened hemisphere of the moon, is perpendicular to the direction of the sun's rays falling upon it; that is, it is perpendicular to the plane of the ecliptic. But the plane which divides the portion of the moon's surface which *may* be seen from the earth from that which *may* not, is perpendicular to a line drawn from the eye of the observer to the moon's centre; this plane is, therefore, variable with the position of the observer on the earth, and the position of the moon in the heavens above him; if the moon were in his zenith, this line would be exactly that joining the earth's centre and the moon's; and there will be no great error in supposing it always to have that direction. The plane dividing the part of the moon which can be seen from that which cannot, is then perpendicular to the plane of the moon's orbit; and the intersection of this plane with the plane perpendicular to the ecliptic which bounds the enlightened and unenlightened portions of the moon, is the line which joins the horns of the moon; thus this line joining the horns is nearly perpendicular to the ecliptic, deviating not more than 5° 9′ from it.

## XXXVIII.

### Day and Night in the Moon.

By observations which have been made on the spots on the moon, it has been ascertained that she always turns *the same portion of her surface, i. e.,* the same hemisphere *towards the earth;* whence it follows that she must in each revolution round the earth, turn round upon herself in a plane parallel to the plane in which she moves. This phenomenon will be understood by an illustration: if a person walk round a tree, keeping his face continually towards it, he must, to do this, when he has walked round the tree, have at the same time turned completely round upon *himself;* this will be *evident,* if we reflect that in thus moving round the tree, he will have seen completely round the horizon, to effect which, he must, of course, have turned himself completely round. Instead of revolving once in every twenty-four hours about her axis, as our earth does, the moon revolves therefore once a month. Thus the lunar day is about fifteen days in length, and the lunar night fifteen days. In nineteen years, there are to the inhabitants of the moon, only 235 nights and 235 days. The heat accumulated through each fifteen successive days of sunshine, and the cold produced by the radiation of this heat during 15 days of continual night, must each be excessive, and each alternation of day and night present the miniature image of a *season* of fiery heat and of intense cold.

So slow is the revolution of the moon upon her axis, and so slow, consequently, is the progress of the boundary of light and darkness over her surface, that it would be possible, perhaps, to outstrip it, and travel faster than the day. Thus completing the circuit of his planet every month, a lunarian might live in perpetual sunlight and continual heat, an expe-

dient which the intense cold of the lunar night would not fail to suggest to him.*

## XXXIX.

### The Appearance of the Earth from the Moon.

Since the moon presents always the same hemisphere to the earth, and turns away always the same hemisphere or side of her surface from it, it is evident that the earth can only be visible at any time, from one half of the moon, the inhabitants of the other, if there be any, never seeing it, unless they pass the boundary which divides it from the first. To those inhabitants of the moon who can see the earth, it presents the appearance of phases like those which the moon presents to us, but on a far larger scale; first they see a crescent, thirteen times greater than that of the moon to us, then a half circle of corresponding dimensions, and lastly, a full orb, spreading itself over a vast space in the heavens, presenting to them, as the earth turns rapidly upon its axis, in the succession of portions of its surface, covered by water, or broken into the inequalities of the dry land, an endless variety of appearance, and, with the changes of the dense atmosphere that surrounds it, colours, probably, of changing hues, and light of varying intensity. This magnificent object thus goes through its series of changes, apparently at *rest*,—*fixed* invariable in the same quarter of the heavens.

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* We have stated that this expedient is possible, and the reader will readily see how. The circumference of the moon is $\frac{3}{11}$ that of our earth, or it is about 6790 miles, which distance might be travelled, at the rate of 226 miles a day, in about 30 days. Now the force of gravity on the moon is only about one-half that at the earth; all the forces tending to retard motion, are, therefore, only one-half.

## XL.

### The Physical Constitution of the Moon.

Seen by the naked eye, *some portions* of the moon's disc appear darker than the rest, and viewed under the telescope, *the whole* of its surface seems covered with irregular markings. These markings may be divided generally into two distinct classes,—those which are *permanent*, presenting precisely the same forms and intensities at all ages of the moon, and those which *vary* continually in form and intensity, with her varying elongation from the sun. The latter have before been stated to be manifestly the shadows of mountains and of cavities, varying perpetually in length, with the variation of the angle at which the sun's rays fall upon those irregularities of the moon's surface of which they are the shadows. For let it be observed, that by reason of the continual revolution of the moon upon an axis within herself, in the period of a sidereal revolution about the earth, the light of the sun is made to fall upon any object on her surface at every possible angle (within certain limits,) in the course of the half of that period, or about fifteen days—precisely as, by the daily revolution of the earth upon its axis, the sun-light is made to fall upon an object on the earth's surface at an infinite variety of different angles within the period of a day, and thus to give shadows of an infinite variety of different lengths.

From the fact that the other class of marks to which we have referred do not present this variety of appearances with the moon's age, we conclude certainly that they are not shadows; but that they result from some peculiarity in the nature of the surface of the mass of which the moon is there composed, affecting the reflection of the sun's rays, and absorbing more of them there than elsewhere.

Some have supposed them to indicate the presence of a fluid. This conclusion, however, is not a necessary one; and

it seems to be contradicted by the fact that the moon has no atmosphere,—a fact which is supposed to be established. It seems pretty certain, that a liquid of the nature of those which exist at the *earth's* surface would, were the atmospheric pressure removed, very soon convert itself into vapour, under the influence of the heat of the sun, and, *à fortiori*, this result might be expected on the *moon's* surface, where the elevation of temperature resulting from each fifteen days of continued sun-light must be enormous.

The principal of these marks have been very accurately observed and laid down upon a map of the moon by Schroeter; and he has given to them the names of Aristarchus, Manilius, Eudoxus, Tycho, Copernicus, Kepler, &c. One of the most remarkable is that called Aristarchus, on the eastern limb of the moon. Luminous points, having the appearance of sparks of fire, have been seen in this spot by Cassini, Herschel, Kater, &c., even at the period of new moon. Of the action of fire on the surface of the moon there are said to be numerous evidences: the cavities have all the appearance of craters: all round their edges appears to be thrown up in immense ridges the matter which must have been removed to form them. These ridges Herschel asserts to be visibly stratified. From the bottom of one such cup-shaped cavity, a cone-shaped hill will not unfrequently be seen to uplift itself, bearing at its apex another cavity. These are all indications of volcanic action, precisely analogous to indications presented by certain portions of our globe. It requires, indeed, no great stretch of imagination to conceive a period when our earth presented a surface similar to that of the moon, from the bare unfruitfulness of which it has subsequently progressed to its present state of beauty and productiveness.

We have stated it to be a fact which is commonly asserted and believed, that the moon has no *atmosphere:* we have, moreover, stated it to be a received opinion, that *volcanic action* has heretofore taken place to a great extent on the surface of the moon, and indeed, that fire may now occa-

sionally be seen upon it. Now, these opinions appear at first sight to be incompatible; we have no notion of combustion without air,—air being in fact, that compound substance, from the decomposition of which, combustion, with us, at the earth's surface, *results*.

Although there is manifestly a difficulty in this, yet it is not in reality so great as at first sight it may appear to be. Oxygen gas is that constituent of the air which is thus required for combustion; and it is ascertained that there are certain bodies, which, in the course of their decomposition, supply sufficient of this principle for their own combustion.

## XLI.

### Has the Moon an Atmosphere?

That the moon has no atmosphere is said to be proved by the fact, that the time of the occultation of a fixed star would not be that which we observe it to be, if such an atmosphere existed. An atmosphere like ours must, as will be afterwards explained, have the power of *refracting*, or turning at an angle, the directions of the rays of light falling from such a star obliquely upon it: when, therefore, the *direct* rays of the star are intercepted by the intervention of the moon's body, certain others would, by means of this refraction, be so turned as to come into the eye, and the star would be visible even when it was behind the moon; thus we should see it for some time after the moon had in reality covered it, and for some time before it left it; and the length of the obscuration would thus be less than the time actually necessary for the moon's disc to pass over the star; which time may be calculated from the known period required by the moon to pass over a degree of the heavens, and the known angular width of the disc at the point where the occultation takes place. There are, indeed, certain densities of the lunar

atmosphere which may be conceived, such that a star should be visible throughout the whole occultation, or rather, that there should be no occultation at all.

All this reasoning, and it is the only reasoning on which the conclusion that there is no lunar atmosphere is founded, proceeds on the supposition that the existence of such an atmosphere necessarily implies the existence of a power of refracting light, analogous and *proportional* to that of our own atmosphere.

If there be no atmosphere on the moon, it is difficult to conceive the existence of living beings upon it, either vegetable or animal. Do such living beings, however, exist there, and did we think it worth while to speculate about them, reasoning by analogy, we might arrive at the conclusion that their strength and stature must be less than ours. All those objects, for which a certain share of strength and stature are given to us, could by them be effected with about one-sixth of these. The force with which bodies are attracted to the surface of the moon is about one-sixth of that by which similar bodies are attracted to the centre of the earth: so that any object which a lunarian might wish to lift, he would lift with one-sixth the muscular exertion required to lift it here, and to accomplish the same purpose he would require only one-sixth the muscular strength. The surface of the moon, too, is only $\frac{3}{40}$, or about $\frac{1}{13}$ that of the earth, and its circumference $\frac{3}{11}$, or about one-fourth, so that he might obtain the same proportion of locomotion on its surface, and appropriate to the uses of his own existence about the same proportion of it, with about one-sixth or one-eighth the same actual change of place. His limbs need not then be of the same dimensions; and if the vegetable and other animal existences around him be adjusted to the same scale, his stature need not be so high, or his bulk so great.

## XLII.

### The Elliptic Form of the Moon's Orbit.

We shall pass now to the discussion of certain other appearances of the moon's disc. In the first place, then, it is observed not, at all periods of its age, to be of the same size. If measured accurately with a micrometer, its diameter will be found in the course of a single lunation to vary from 29′ 21·91″ to 33′ 31·07″, the ratio of which numbers is nearly that of 7 to 8. This is a much greater variation in the angle which it subtends to an observer on the earth, than the similar variation which takes place in the apparent diameter of the sun in the course of a year.* Now, if any number of apparent diameters intermediate to these be observed, and also the corresponding longitudes, precisely the same relation will be found to exist between them as was found to exist in the case of the sun, from which relation it was shown that the distances of the earth from the sun were those of the circumference of an ellipse from its focus. Moreover, the law will be found to obtain, that the angle described in a given small time, an hour, for instance, being divided by the square of the apparent diameter, or, which is the same thing, being multiplied by the square of the radius vector, the result is *always the same*. From these facts, then, we deduce the conclusion that the moon moves round the earth in an orbit which is not a circle, but an ellipse, or very nearly so; and that its motion in that ellipse is governed by this remarkable law, that the area described or swept over in a given time by the radius vector is always the same; the orbit of the moon round the earth precisely resembling in these respects the

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* The diameter of the sun varies from 31′32″ to 32′ 35″; so that the moon is sometimes apparently less, and sometimes greater, than the sun.

orbit of the earth round the sun, but having a much greater eccentricity.*

But not only is there this variation in the apparent diameter of the moon at different ages during the period of the same revolution, but there is an analogous variation in her apparent diameter at the same ages of different revolutions. Thus, for instance, if the moon's apparent diameter be observed *when she is full* for a succession of different lunations, it will be found, that in a certain period the diameter will go through every possible variety of change between the extreme limits of 29′ 21·91″ and 33′ 31·07″, being in no two successive lunations the same, and returning to the same value only after the expiration of this period.

## XLIII.

### Eclipses of the Moon.—To calculate whether an Eclipse of the Moon will in any particular Month occur.

The earth being an opaque body, a certain portion of the light of the sun is intercepted by it, and a dark shadow projected behind it in space. Being of less dimensions than the sun, this shadow is *cone-shaped*, having its apex in that line, produced, which joins the centres of the earth and sun, and for its base that section of the earth through its centre which is perpendicular to this line. Moreover, this cone, if produced, would have a section of the sun for its base. The cone, therefore, is such, that sections of the earth and sun would be sections of it at a distance equal to that of the sun

* The eccentricity of the moon's orbit is more than *thirty* times greater than that of the earth, that is, it deviates thirty times more from a circle, or is thirty times more oval, or elongated. The eccentricity of the earth's orbit is ·01685, that of the moon's ·5485.

from the earth. Hence, knowing these sections and this distance, we can tell what are the precise dimensions of the cone.

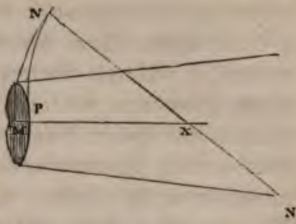
The distance of its apex from the centre of the earth is thus found to vary (as the earth's distance from the sun varies) from 212 to 220 radii of the earth, or from 838,500 to 870,003 miles. Moreover, the moon's distance from the earth is not more than $60\frac{1}{4}$ radii of the earth, or 238,361 miles. Hence, therefore, if the moon's motion round the earth were in the plane of the ecliptic, or in that plane which is swept out by the line joining the centres of the earth and sun, then at each revolution its centre would cross that line; it would pass through the very axis of the cone and the centre of the shadow, and the section of the shadow being there somewhere about seven times and one-ninth the section of the moon, it follows that the moon would be for some time wholly immersed in the shadow, and thus receiving no light from the sun, would be invisible to us, or eclipsed, as it is termed, once in every successive lunation. Moreover, supposing the moon's orbit not to be in the plane of the ecliptic, as it really is not,—if, nevertheless, its inclination were such as to cause the moon to pass within a distance equal to one of its radii, from the surface of the shadow, then, as before, would a part, if not the whole of the moon, be carried at each revolution into the shadow, and a certain part, or the whole, receiving no light from the sun, would be invisible. We may easily find what must be the limit of the inclination of the moon's orbit, that an eclipse may thus take place at every successive lunation.

The figure on the next page represents the shadow which the earth casts out behind it, into space, in its correct proportions. A B is that section of the earth which is its base, M N the section of the shadow at the distance of the moon's orbit, and $q$ $r$ a section of the moon.

If we add together the angles $p$ C $q$ and $q$ C $r$, we manifestly get $p$ C $r$, which is the inclination of the orbit in which,

if the moon revolved, and the line in which its plane intersects the plane of the ecliptic were a tangent to the earth's orbit, her disc would at every revolution just touch the surface of the cone. This inclination is therefore the limit of all those at which an eclipse could take place at *each* revolution. Now the angle $p$ C $q$ is that made at the earth by the radius of the section of the shadow, where the moon enters it, and is easily calculated to have for its least value 37′ 42″. Also the angle $q$ C $r$ is the apparent semi-diameter of the moon, and its least value is 14′ 41″. So that the sum of these, or 52′ 23″, is that inclination, which, if the inclination of the moon's orbit did not exceed, and if the line of the moon's nodes were always a tangent to the earth's orbit, there would be an eclipse *every month*.


Although, if the inclination exceed this limit, an eclipse does not thus *necessarily* occur every month, yet it *might* so occur. We have here supposed the intersection of the plane of the moon's orbit with the plane of the earth's to be in the earth's orbit; so that the line of nodes might coincide with the line of the earth's motion, and thus the greatest distance of the moon's orbit from the plane of the earth's, and from the centre of the shadow, be, when the moon was in opposition. Now this is by no means a necessary supposition. The line of the nodes, instead of making an angle of 90° with the axis of the shadow, might be always inclined to it, only at a very small angle.



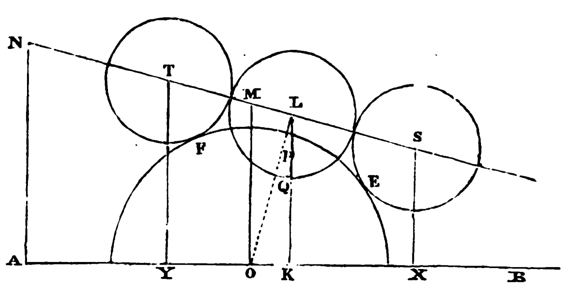

Thus, if M X were the axis of the shadow, and M P the section of it, where the moon enters it, and N N′ the line of the nodes, then, whatever was the inclination M N P of the plane of the moon's orbit, N P, the position of N N′ with respect to M X might be such, that is, it might be so near it, as to cause the orbit N P to pass *through* the shadow. And in this case, provided that N N′ and N X retained always this relative position, that is, *supposing the line of the moon's nodes revolved always with the same angular velocity as the axis of the shadow does, or as the earth itself does*, then would the same lunar eclipse occur at the same period of each successive lunation. But this is not the case: the line of the nodes revolves, as we have seen, but its angular revolution is not the same as that of the earth in its orbit. The revolution of the earth is completed in a mean solar year; whereas the revolution of the nodes takes 18·6 such solar years to complete it. Thus, then, it is manifest, that the line of nodes does not retain the same position in reference to the axis of the shadow at each successive opposition, but that it takes every possible direction in regard to it, and therefore, that there cannot possibly be a lunar eclipse every month. Nevertheless that in this variety of positions of the line of nodes there must, of necessity, be some in which it is so near to the axis M X of the shadow, that traversing its orbit N P, the moon shall, partly, if not wholly, enter the shadow. The least angular distance of the two at which this can take place is 12° 36′, and is called the lunar ecliptic limit. If, at the time of any opposition, the line of nodes be inclined to the axis of the shadow, at an angle less than this, *there must be an eclipse.* The axis of the shadow being always in the line joining the earth and sun, it is evident that it revolves through the ecliptic with the sun, or with a mean motion of 59′ 8″ daily. Moreover, it is

shown that the regression of the line of nodes on the ecliptic is 3′ 10″ daily. Thus, knowing the rate at which these lines revolve, if we knew their position in respect to one another at any given time, we could find it any other time. Such positions are known from observation, and the corresponding times serve as epochs whence the position of the line of nodes in respect to the shadow, may at all other times be found. We may thus, then, find the inclination of the line of the nodes to the axis of the shadow at every *opposition* of the moon to the sun, that is, at every full moon. *At every such opposition where this inclination is less than the lunar ecliptic limit of* 12° 36′ *there will be an eclipse.*

## XLIV.

### To calculate how much of the Moon will be Eclipsed.

Let us suppose that the position of the moon's node at the time of an opposition is thus known, and that this is, in reference to that opposition, within the lunar ecliptic limit of 12° 36′.




Take a line A B, and suppose it to represent a portion of the ecliptic, let the point O represent the place of the centre of the earth's shadow at the moment of opposition, and from any scale of equal parts take the perpendicular O M, containing as many of those parts as there are degrees, or rather minutes,

in the moon's latitude* *at the moment* of opposition. M will then be the place of the moon's centre in opposition. And take A O to contain as many of the same parts as there are minutes in the horary motion of the moon's centre diminished by the horary motion of the centre of the shadow (about 30′). From A draw the perpendicular A N, equal on the same scale to the moon's latitude, one hour *after* opposition. If M N be then joined and produced, it will be what is called the moon's *relative orbit.* Being an orbit which, if it described, it would come precisely into the same positions with regard to the centre of the shadow O (which is supposed at rest) as it actually does come into, with respect to that point in motion. Draw the perpendicular O L upon N M; then will this be the shortest distance off the point O from the moon's orbit, or the shortest distance within which the centre of the moon comes to the centre of the shadow; and if we ascertain how many equal parts of our scale are contained in this line, we shall know how many minutes there are in the least apparent distances of the centres of the moon and shadow. From the centre L, with radius equal to as many equal parts as there are minutes in the moon's semi-diameter, describe a circle: it will represent the space which the moon's disc covers in the heavens. It remains now only to find the number of minutes in the apparent semi-diameter of the section of the shadow; and when this is known, to describe from O a circle E F, having a radius of as many equal parts as there are minutes in this: the space of the heavens covered by the shadow will be represented by this circle, and the amount of the eclipse ascertained by its interference with that circle which represents the moon's disc.

Now the angular semi-diameter of the section of shadow is equal to the angle under which the earth's semi-diameter would be seen from the moon, diminished by the sun's apparent semi-diameter. This is easily proved.

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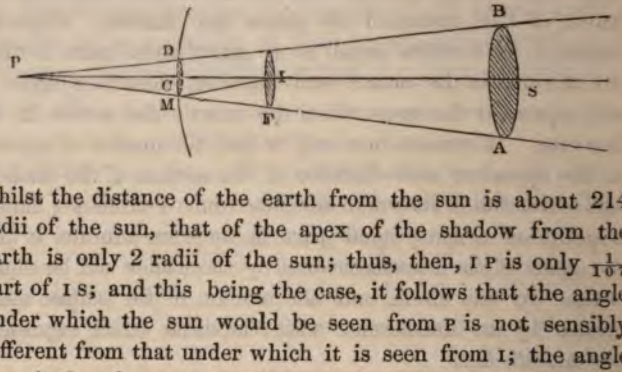
* These data may all be found in the *Nautical Almanac.*

Let A P B represent the shadow, I the centre of the earth, and M D the section of the shadow; then will C I M be the angle under which the semi-diameter of the shadow is seen from the earth; or it will be that apparent semi-diameter of the shadow which we want. Now, since I M F is the exterior angle of the triangle P M I, therefore it is equal to the two interior angles M P I and M I P; and therefore P I M is equal to F M I diminished by M P I or A P S. Now, I M F is the angle under which the earth's semi-diameter would be seen from the moon; and A P S is the angle under which the sun would be seen from the apex P of the shadow. Now, since the sun's diameter is exceedingly great as compared with that of the earth, it follows that the apex of the shadow is exceedingly near to the earth as compared with its distance from the sun; that is, because A S is very great as compared with I F, it follows that I P is very small as compared with I S: in point of fact, it will be found that




whilst the distance of the earth from the sun is about 214 radii of the sun, that of the apex of the shadow from the earth is only 2 radii of the sun; thus, then, I P is only $\frac{1}{107}$ part of I S; and this being the case, it follows that the angle under which the sun would be seen from P is not sensibly different from that under which it is seen from I; the angle A P S is therefore very nearly equal to the sun's apparent semi-diameter, and it follows that the radius of the section of the shadow is very nearly equal to the angle under which the earth's semi-diameter would be seen from the moon, diminished by the sun's apparent semi-diameter. Both these quantities are variable, but they are stated for every day of

the year in the tables of the *Nautical Almanac*, and other ephemerides. Take them, then, corresponding to the time of the opposition, subtract them, take in the compasses as many equal parts from the scale as there are minutes in the difference, and describe a circle having the point O for its centre (fig. page 134): if this circle intersect that which was before described, having L for its centre, there will be an eclipse; if not, there will be none. Moreover, the quantity of the interference of the two circles will mark the degree of obscuration when it is greatest: thus, in the figure, the two circles over-lapping one another by a distance equal to P Q, if this distance be measured on the scale of equal parts, as many of those parts as are contained in it, so many minutes of the moon's disc will be eclipsed. But the usual method of designating the amount of the eclipse is to divide the whole diameter of the disc into twelve equal parts, called digits, and ascertain how many of these are in the width, P Q, of the obscured portion.

## XLV.

### To Calculate the Time of Greatest Obscuration, and the Times of the Commencement and Termination of the Eclipse.

To find the exact *time* of greatest obscuration, we have only to draw from L (see fig. page 134), the perpendicular L K on A B, and ascertain how many parts are in O K; this will give the number of minutes of longitude through which the moon's centre moves, in reference to the centre of the shadow, between the time of greatest obscuration and the time of opposition. Now, knowing the relative motion of the moon and shadow in longitude for an hour, we can tell how long they will take to accomplish this number of minutes of relative motion; thus, then, we shall know how much before or after the time of opposition it is that the greatest obscuration

took place; and similarly, if we find points T and S in the relative orbit N S, such that circles described from these points, representing, as before, the moon's disc, may just *touch* the circle which represents the shadow in E and F, and having found these points T and S, if from them we draw perpendiculars, T Y, and S X, upon A B, then O X and O Y will represent the relative motions in longitude of the moon and shadow between the time of opposition and the times of the commencement and termination of the eclipse respectively; and knowing the hourly amount of this relative motion, we can find, as before, the time from opposition of the commencement and end of the eclipse. Thus all the circumstances of the eclipse may be determined with considerable accuracy by a very simple construction, and the most elementary processes of arithmetic.

Let us now proceed to the subject of the eclipses of the sun.

## XLVI.

### A TOTAL SOLAR ECLIPSE.

Not only does the earth, being an opaque body, throw into space a dark shadow, which, by reason of its diameter being greatly less than that of the sun, is of the form of a *cone*, terminating in a point whose distance is from 838,500 to 870,003 miles from the earth's centre, but which is, although so enormous a distance, nevertheless only $\frac{1}{107}$ of that of the sun; but the moon, also, for like reasons, darts her conical shadow outwards into space,—a shadow whose termination is at a less distance from *her* centre than the earth's from the earth's centre, in the proportion in which she is less when compared with the sun, than the earth is, when compared with him.

Since the termination of the moon's shadow is formed by the intersection of lines drawn touching the opposite extre-

mities of diameters of the sun and moon, it follows that to an observer at a distance from the sun equal to that of the termination of the shadow, the sun and moon would appear precisely under the same angle; and conversely, if the sun and moon appear under the same angle to an observer, then he knows that he is at the same distance from the sun that the apex of the shadow would be. Now, the moon appears to us sometimes under precisely the same angle as the sun, sometimes under a greater angle, and sometimes under a less: we know, then, that we are sometimes at the same distance from the sun that the apex of the shadow is, and *in the very place* where it would be if the moon came between us and the sun; and we know, also, that we are sometimes at a less, and sometimes at a greater distance. Now, we know that by reason of the small inclination of the moon's orbit, and the motion of its nodes, it must sometimes intervene exactly between us and the sun; we know, then, that we *may* be, and *shall* be, sometimes, in the *very apex* of the shadow; at others, plunged *some depth* into the conical extremity of it; or that, in other cases, the apex of the shadow must lie in a line between us and the sun, but nearer the sun. In the conical shadow there is absolutely no light, (except, perhaps, some little reflected from the earth, called earthlight;) when, therefore, we are in the apex of the shadow, or immersed any depth in it, we can receive no light, and the sun must be invisible, or there must be a total eclipse. Thus it is proved that the shadow of the moon is of such a length as sometimes to be long enough to reach the earth, and that its motion is such as to sweep this shadow, which is thus long enough, sometimes across it. The greatest area which the shadow of the moon can cover upon the earth is a circle of about 180 miles in diameter: the actual spot thus covered is, of course, perpetually varying with the relative motion of the earth upon its axis, and the synodical motion of the moon.

Such are the conditions of a *total* solar eclipse. It is

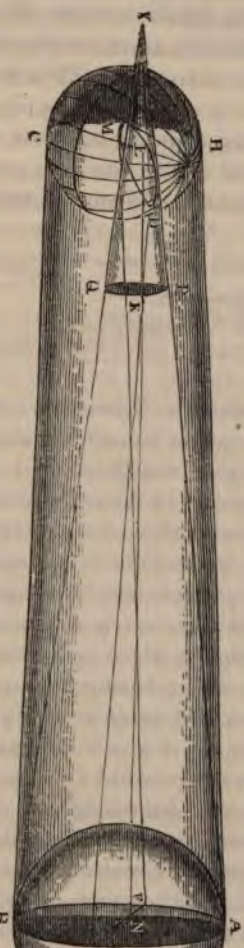
manifest that such an eclipse can be visible only at those places over which the tail of the shadow is made by the combined rotatory motion of the earth and the synodic motion of the moon to sweep. This is not, however, by any means the most general way of looking at the question: an infinity of eclipses of the sun may occur besides the total eclipse; and these may be brought about without the apex of the shadow anywhere coming in contact with the earth's surface.

Let us consider the more general conditions of a solar eclipse.

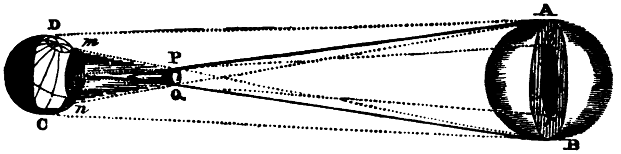
## XLVII.

### General Conditions of an Eclipse of the Sun.

Let A B H C represent the cone of light which falls from the sun upon the earth. Now it is clear that the moment the moon, or any portion of the moon, enters this cone, a portion of the light which falls upon the earth must be intercepted somewhere or another. A portion, or the whole, of the rays which fell before from the sun do not now fall there. Let P Q represent a section of the moon partially immersed in the cone of sunlight; and let M D represent the intersection of its shadow with the surface of the earth; then it is clear that at every place within the space M D a portion of the sunlight will be intercepted. At L this portion may be ascertained by joining L K, and producing this line to the sun in N, K being any point on the circumference of the moon's disc within the shadow. No light coming from the portion of the sun N E can, evidently, reach an observer at L; nevertheless the whole light between N and F will come freely: thus the sun will be eclipsed to the observer at L to the extent E N; and if the point K be supposed to traverse that portion of the circumference of the moon's disc which is within the shadow, the line L K N being continually drawn through it, the point N will trace out a line A N B on the sun's disc, which will be



the boundary of its bright and its obscured part, as seen from L. To observers at points between this and D, it will be similarly eclipsed, but to an extent less than this, until at D the very edge of the solar disc only is interfered with, and scarcely any eclipse is visible; and on all points without M D the sunlight falls freely, and no eclipse is seen: thus, then, it appears that a partial eclipse may take place when the moon is not wholly immersed in the cone of sunlight.




Again, let the disc P Q of the moon be wholly included in the cone of sunlight; join A Q, and produce it to *n*, and join B P, and produce it to *m*, and let lines be similarly drawn from all the other points in the sun's disc touching the surface of the moon, and enclosing the portion *m n* of the surface of the earth. Then, without this space *m n*, none of the sunlight will be intercepted, and no eclipse will be visible. At any point *h* within the space *m n*, a portion of the sunlight will be intercepted, which may be determined by drawing lines *h* P and *h* Q, &c., touching the surface of the moon, and producing them to the sun's disc in *q r*, &c. It is evident that these points *q r*, &c., will lie *within* the sun's disc, and that the whole space included by them will be obscured to the observer at *h*, whilst the light will come freely to him from the space without them. Thus the eclipse will be to him an annular eclipse, the circular portion, *q r*, of the disc only being obscured. If, however, the shadow, instead of terminating, as shown in the figure, at a distance from the earth, sweep its surface, the space *q r* will, if *h* be within the area covered by the shadow, swell so as to include the whole solar disc A B, and the eclipse will be total. The space *m n*, within which an annular or total eclipse must occur, is called

the penumbra, as that covered by the actual shadow is the umbra. It has been shown that the umbra may cover a space of 180 miles diameter on the earth's surface; the penumbra may cover 4900 miles.

## XLVIII.

### To Determine whether the Moon will at any given New Moon intercept any of the Light which falls from the Sun upon the Earth, or not.

In determining the circumstances of a solar eclipse, the first step is manifestly to ascertain the precise moment when the moon first enters the cone of sunlight, so as to intercept the rays which would otherwise fall upon the earth,—to ascertain, further, the moment of its greatest immersion, and the depth of that immersion, and lastly, the time when it emerges from the cone of sunlight. These points being determined, it will yet remain to fix upon all those places of the earth's surface where the rays intercepted during the period of this immersion would otherwise have fallen; that is, to determine the various places where the eclipse will be visible. The determination of the time when the moon first enters the cone of sunlight, bears a close resemblance to that of the time of its entering the earth's shadow, which we have described in treating of eclipses of the moon: in fact, the shadow is (geometrically) but a continuation of the cone of sunlight, so that, in fact, the circumstances of the entrance of the moon into the earth's shadow, and its entrance into the cone of sunlight falling from the sun to the earth, are but the circumstances of its entrance into different portions of the *same* conical surface.

It is manifest, for the same reasons as those given in the case of the lunar eclipse, that this immersion cannot take place except when the longitude of one of the moon's nodes is nearly the same with that of the sun. At points of the

cone of sunlight where the moon can enter it, the circular space in the heavens occupied by a section of the cone of sunlight, can never have a radius greater than 1° 35′ 4″, or less than 1° 24′ 0″; and since this circle has, of necessity, its centre in the ecliptic, it is clear that the moon cannot enter at all the cone of sunlight when its latitude is greater than 1° 35′ 4″, and that it must, of necessity, enter it, if at the period of its conjunction, its latitude is less than 1° 24′ 0″. Now it has the latitude 1° 35′ 4″ when distant 19° from its node, and the latitude 1° 24′ when distant 13° 42′ from its node; thus, then, if at the time of its conjunction with the sun it be distant more than 19° from its node, there can be no eclipse; if it be distant less than 13° 42′, there must, of necessity, be an eclipse; and if its distance from its node be anywhere between 19° and 13° 42′, an eclipse may possibly, but will not necessarily, occur: these are called the solar ecliptic limits.

## XLIX.

### To Determine the precise Time and Amount of the Immersion of the Moon in the Cone of Sunlight.

Let us now suppose it to be determined that the distance of the moon from its node at conjunction is less than 13° 42′, so that it *must* be immersed in the cone of sunlight; and let it be required to determine when the immersion does take place, and under what circumstances. In the first place, we must know the radius of the section of the cone at the distance where the moon will enter it. Now it may be shown, by reasoning similar to that applied to determine the section of the shadow in the lunar eclipse, that the radius of the cone of sunlight is at this point equal to the apparent semidiameter of sun + the angle under which the earth's radius is seen from the moon — the angle under which the earth's radius is seen from the sun. Now, these are quantities

which are all given* by the tables, and may be there found for the time of conjunction: thus, then, the angular radius of the section of the cone of sunlight where the moon enters it, may be determined.

Take, then, from a scale of equal parts, a number equal to the number of minutes in this angle†, and describe a circle E F (see fig. page 134), having this length for its radius. Take A B passing through the centre O of this circle, to represent the ecliptic; let O A represent, on the same scale, the number of minutes in the relative motion of the sun and moon in longitude in an hour; and A N, perpendicular to A B, the moon's latitude one hour after conjunction; also let O M represent the moon's latitude at the moment of conjunction; and join M N, and produce it; then will the motion of the centre of the moon, in respect to the centre of the section of cone of sunlight, be the same as though the centre of the cone of sunlight remained at rest at O and the centre of the moon moved in the orbit M N, M N being what is called the *relative* orbit.

If from O there be drawn the perpendicular O L upon M N, intersecting the circle E F in P, and P L be measured on the scale, so as to find how many of the equal parts used are contained in that line, then if the number of these exceed the number of minutes contained in the moon's semi-diameter, the moon will not anywhere enter the cone of sunlight, and no eclipse will anywhere be visible : if it be less than that number, there will be an immersion; the greatest quantity of that immersion being measured by the difference, P Q, of these numbers.

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* The angle under which the earth's radius would be seen from the sun may be considered constant, and equal to 9″; the greatest and least values of that under which it would be seen from the moon, are 62′ and 53′; and the greatest and least apparent semi-diameter of the sun are 15′ 45″ and 16′ 18″.

† Its mean value may be taken at 73½′.

Moreover, if points S and T be found in the relative orbit, from which circles being described, having for their radii each the number of parts in the moon's semi-diameter, will just *touch* the circle E F in the points E and F, then will these be the points where the moon first enters the cone of sunlight, and where she leaves it. And if from S, L, and T, perpendiculars S X, L K, T Y, be drawn upon A B, then will the distances O X, O K, O Y, be those which the moon will have to describe, in its relative motion in longitude, between the period of its first immersion in the sunlight at E, and its conjunction between its greatest immersion at P, and its conjunction, and between its conjunction and its emersion at F.

Now, the space through which the moon moves in an hour, with its relative motion, being known, it is evident that we can find the time which it will require to describe with that motion these spaces O X, O K, O Y; thus, then, we shall find the times from conjunction of the first immersion of the moon in the cone of sunlight, of its greatest immersion and of its emersion.

Throughout the period whilst the moon is thus partly or wholly within the cone of the sun-light, it is obstructing some of the rays which would otherwise fall from the sun to certain parts of the earth's surface, and producing there a partial, or perhaps total eclipse. It remains now to examine what are those places of the earth where any eclipse is visible, and under what circumstances. For this purpose we must discuss the question of parallax.

## L.

## PARALLAX.

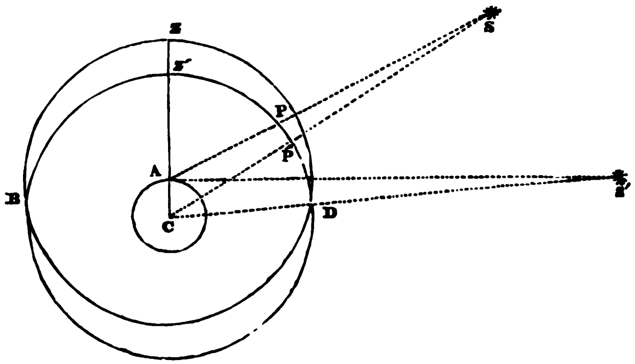
That sphere of the heavens to which we refer the positions of all the heavenly bodies, and in degrees of which sphere, we estimate their longitudes and latitudes, declinations and right ascensions—measures which serve to ascertain their

positions on it,—this imaginary sphere of the heavens is *not*, in reality, the sphere which we *see* around us, when we look out upon the heavens. It has its centre in the centre of the earth, whereas that which we actually see has its centre in the eye of the observer, who is placed on the surface of the earth. Now, it has been before shown, in the course of these pages, that because of the enormous distance of the region of the fixed stars, they appear to us precisely in the same position, on the sphere which we actually see from the earth's surface, as they would upon a sphere whose centre was the centre of the earth, could the eye look upon that sphere from thence. This conclusion, which is perfectly true with regard to the fixed stars, is not, however, true in reference to the sun and planets, forming that system of the universe, which, by reason of our more immediate relation to it, we call our own; and especially it is not true in reference to the moon. All the bodies of our system are infinitely nearer to us than the fixed stars, and they do not appear upon that visible sphere of the heavens upon which we see them, as they would appear upon a sphere having the earth for its centre, could we see them from that point.

Let A be the position of the observer at the earth's surface, and B Z D the sphere of the heavens which he sees, and whose centre is A. Also, let C be the earth's centre, and B Z′ D the sphere of the heavens which he would see if his eye were *there*. Let S be any heavenly body not at an infinite distance as compared with A C. Join S A and S C, then will P and P′ be the points where S will appear on the spheres B Z D and B Z′ D respectively, and as seen from A and C. Also, if C A be produced intersecting the spheres in Z and Z′, then will these points be the apparent zeniths of the two observers at A and C, and Z P and Z′ P′ will be the apparent zenith distances of S, as seen by them from those points.

Now Z P contains as many degrees as there are in the angle Z A P, and Z′ P′ as many as there are in Z′ C P′ and Z A P is greater than Z′ C P′ (*Euclid*, 1—16), therefore Z P is greater

than Z′ P′. That is, the apparent zenith distance of S is not the same as it would have been if seen on a sphere having its centre at the earth's centre, instead of at the earth's surface, or its place on the great imaginary sphere of the heavens is not the same as its place on the sphere on which it is actually seen; the difference between these is called the PARALLAX.




In the case we have supposed, it is manifestly equal to the difference of the arcs Z P and Z′ P′, or the angles Z A P and Z′ C P′. Now, the difference of these angles is (*Euclid*, 1—33) the angle A S C; the angle A S C is, therefore, the parallax. Also, knowing what is this angle A S C, and observing Z P, we can tell what is Z′ P′; that is, observing the place of S on the apparent sphere of the heavens, and knowing the parallax, we can tell what is its place on the true astronomical sphere of the heavens, whose centre is the centre of the earth. It is clear that the value of the parallax A S C is greater or less as S is more distant from, or nearer to the zenith. It is greatest when S is at S′, 90° from the zenith, or in the horizon; and it vanishes altogether when S is in the zenith.

The parallax of a heavenly body when in the horizon, is called its HORIZONTAL PARALLAX. Join S′ A and S′ C, then is A S′ C the horizontal parallax of S, it is equal to the angle

under which the semi-diameter, C A, of the earth would appear to an observer from S′. Knowing the horizontal parallax of S, we can tell its actual distance, C S, from the centre of the earth; for in the triangle C A S′, whose angle A is a right angle, we know C A, the radius of the earth, and the angle C S′ A, whence we may find C S′ or C S.* Also knowing C S and C A, and the apparent zenith distance Z A S, we can, by the known rules of trigonometry, find the angle A S C;† that is, we can find the *parallax*, corresponding to any zenith distance of S, knowing only the *horizontal* parallax, or knowing the distance of S; and thus we are enabled, from the observed place of a heavenly body on the apparent sphere to tell what would be its place on the true astronomical sphere of the heavens, having its centre in the centre of the earth. This is called *correcting for parallax:* and all those observations on the sun and moon which we have hitherto described, and which we have supposed to fix their true places in the great astronomical sphere of the heavens, must be imagined to have been thus corrected.

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* $\text{C A} = \text{C S}' \text{ Sin. A S}' \text{C};$

$$\therefore \text{C S}' = \frac{\text{C A}}{\text{Sin. A S}' \text{C}}.$$

† $$\frac{\text{Sin. A S C}}{\text{Sin. Z A S}} = \frac{\text{C A}}{\text{C S}};$$

$$\therefore \text{Sin. A S C} = \frac{\text{C A}}{\text{C S}} \text{ Sin. Z A S}$$

Now, by the preceding note, $\frac{\text{C A}}{\text{C S}} = \text{Sin. horizontal parallax};$

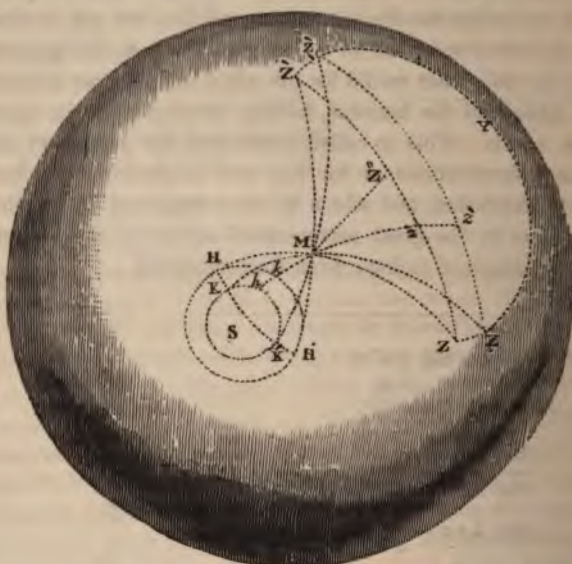
$\therefore$ Sin. parallax = (Sin. horizontal parallax) × Sin. zenith distance. Since the parallax is in all cases a very small angle, its sine may be considered equal to the angle itself;

$\therefore$ parallax = (horizontal parallax) × (Sin. zenith distance).

## LI.

### Where a Solar Eclipse will be Visible.

We now return to the question, where a solar eclipse will be visible. It being determined (p. 144) that the moon is at any time immersed in the cone of sunlight, let it be required to determine *where* at that instant of time is the sun's apparent eclipse, and how much eclipsed at each place.




Let M and S represent the true places of the centres of the moon and sun at the given instant, as found on a celestial globe. From the centre S, describe a circle H $k$ H′, having for its radius the sum of the semi-diameters of the sun and moon. Take H M and H′ M, arcs of a great circle of the sphere, equal to the difference of the horizontal parallaxes of the sun and moon, and let them meet the circle H H′ in the

points H and H′; continue these arcs to Z and Z′, so that M Z and M Z′, may each equal 90°. Through any point, *k*, in the circle H H′ and between H and H′, draw an arc *k* M of a great circle, and produce it to *z*, so that M *k* may equal M H × sin. M *z*, and let the dotted line Z *z* Z′ be the locus of points similar to *z* found corresponding to each of the points in H *k* H′; then at all the places whose zeniths are in the line Z Z′, the discs of the sun and moon will be seen just in contact with one another. If K *h* K′ be any other circle less than H *k* H′, but having the same centre S, and if from the centre M an arc H K K′ H′ be described, cutting this circle in K and K′, and if the points ,Z ,Z′ and *z*′ be taken in reference to this circle, as Z, Z′ and *z* were in respect to the other; moreover, if the line ,Z *z*′ ,Z′ be the locus of all the points similar to *z*′, then at all the places whose zeniths are in this line, the sun will appear to be eclipsed by a quantity, H K, equal to the difference of the radii of the circles H *k* H′*.

* The following is the proof of this easy method of constructing for a solar eclipse. Let us first take the zenith *z*′; it is required to prove, that at the place whose zenith is *z*′ the sun appears eclipsed by a quantity equal to the difference of the radii of the circles H *k* H′ and K *h* K′. The zenith distance of the moon being at this place M *z*′, if we call its *horizontal* parallax H, it will, by the note to the last article, be depressed by parallax through a space equal to H sin. *z*′ M. Moreover, if H′ be the *sun's* horizontal parallax, the space through which the sun will be depressed by parallax at *z*′ will be H′ sin. *z*′ S. Therefore, the quantity by which the centres of the sun and moon will be brought (vertically) nearer to one another by parallax will be H sin. *z*′ M — H′ sin. *z*′ S; that is, this will be the angular space, measured on the vertical, by which the moon will be made more nearly to intervene between the spectator and the sun, than it would if the spectator were at the earth's centre instead if at the supposed point on the earth's surface. If, therefore, we suppose the apparent position S of the sun to be unchanged by parallax, and the moon M to be moved down on the vertical *z*′ M, which passes through its centre, through a space equal to H sin. *z*′ M — H′ sin. *z*′ S, then will the *relative* positions of the centres of the two be the same as they appear to be to a spectator whose zenith is *z*′. Now, since the centres of the sun and moon are, by supposition, exceedingly near to one another, (the moon being partly or wholly within the cone of sun-light;) moreover,

If there be described an arc z′ Y z of a great circle from z to z′, that arc will be everywhere distant 90° from M, and to every place of the earth's surface whose zenith is in that line, the sun will, at the time supposed, be rising or setting eclipsed, (since he will be at a distance of 90° from the zenith), and to every point whose zenith is included between this arc and the arc z z′, the sun will appear at various distances from the zenith of which the perpendicular distance z M is the least, but in all these positions more or less eclipsed.

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since H′ is very small, it follows that H′ sin. $z'$ $s'$ is very nearly equal to H′ sin. $z'$ M. So that H sin. $z'$ M — H′ sin. $z'$ s is very nearly equal to H, sin. $z'$ M — H′ sin. $z'$ M, or to (H — H′) sin. $z'$ M.

But M $h$ was supposed to be taken equal to M K sin. $z'$ M, and M K is equal to M H, which, by supposition, is equal to the difference of the horizontal parallaxes of the sun and moon, or to H — H′; thus, then, M $h$, or M K sin. $z'$ M, is equal to (H — H′) sin. $z'$ M, or to the *relative* vertical depression of sun and moon; and the *relative* positions of the centres of the sun and moon, as seen by an observer whose zenith is $z'$, are the same as though they were at s and $h$. Now, the radius of the circle H $h$ H′ is equal to the sum of the apparent radii of the sun and moon; if, therefore, the moon's centre were in the circumference of the circle H $h$ H′, her limb, and that of the sun, would appear in contact; but her centre, in reality, interposing between us and the sun, as though it were in the circumference of the circle K $h$ K′, her disc will lay over or overlap that of the sun, by a space equal to the difference of the radii of these circles, or to the sum of them, according as the circle H $h$ H′ lies between M and s, or beyond s, or according as the difference of the horizontal parallaxes is less or greater than the true distances of the centres.

At the points z, and $z'$, the arcs z, M and $z'$ M being each 90°, the expressions (H — H′) sin. z, M and (H — H′) sin. z′ M became each H — H′; now M K and M K′ are each equal to H — H′, so that K and K′ are the corresponding positions of the moon's centre in respect to that of the sun at s; and the same may be proved of the points H, H′, and $k$, and the line z z′, as has been proved of K, K′, $h$, and the line z, $z'$, with this only difference, that to all the points of the earth's surface, whose zeniths are in the line z z′, the discs of the sun and moon only just touch one another, their apparent distances (the radius of the circle H H) being equal to the sum of their semi-diameters, whilst to those whose zeniths are in the line z′ $z'$, the disc of the moon overlaps or eclipses the disc of the sun, by a quantity which was shown before to equal the difference of the radii of the circles H $k$ H′ and K $h$ K′.

Such are the circumstances under which an eclipse of the sun is visible at any instant of the time during which the moon lies more or less within the cone of sun-light, and these being ascertained for all the different periods of the immersion, the eclipse is completely determined.

## LII.

### The Solar System.

Every body is acquainted with the outline of the system of the universe, as described in our elementary books of astronomy. It is a system of such exceeding simplicity, that even at the very earliest period when our attention is directed to it, we at once understand it, and the slightest effort is sufficient in after years to replace it in our memories. A sun fixed at rest in the centre, planets wheeling round it, each in its proper order, and in its own periodic time; Mercury, Venus, the Earth, Mars, Vesta, Juno, Ceres, Pallas, Jupiter, Saturn, Uranus,—the Earth, accompanied by one moon, Jupiter by a group of four, Saturn by seven, and surrounded by a ring, Uranus by six,—these facts, remembered probably in connexion with the period and distance of each planet, constitute The Science of Astronomy, as it commonly exists in men's minds—and a prodigious amount of knowledge it is, if we estimate it by the years of laborious observation, the multitudinous theories, and the complication of systems, out of which it has resulted. This accumulation of labour, and the variety of these abortive systems, are, however, things which we find the greatest difficulty in reconciling with the exceeding simplicity of the system itself. And from the time when we first looked at a chart of the solar system, or learned those rhymes which make the sublime doctrines of Copernicus easy to the comprehension of children, we accustom ourselves to wonder that so simple a thing as the Copernican system should have

been so long in being found out. In the eight or ten black circles which we see marked upon our maps of the solar system, we look in vain for *the difficulty;* and thus one of our earliest emotions of unlearned contempt is accustomed to associate itself with the names of such men as Plato, and Aristotle, and Ptolemy, who taught that the earth was the centre of the universe, and that the planets revolved in various and complicated ways about it,—and the weak invention of Tycho Brahé, who thought that whilst the other planets revolved round the sun, the sun itself, with these, revolved round our planet. *Our* acquaintance with the solar system is derived from books and engravings; those men got *theirs* from an actual survey of the heavens; and were not their knowledge of practical astronomy otherwise ascertained, these very theories, false and complicated as they are, would be sufficient to prove it to have been extensive and accurate. The fact is, that the motions of the heavenly bodies, and especially of the planets, simple as they are in reality, are, in *appearance*, complicated in the highest possible degree.

## LIII.

### The Apparent Motions of the Planets.

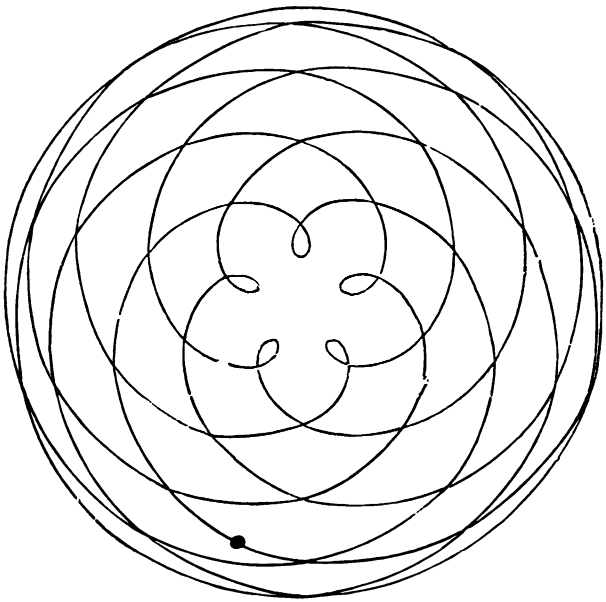
Let us suppose that, throwing aside books, and resolute to discard previously-formed opinions, until we shall have ourselves verified them—provided, moreover, with a micrometer, fitted to a good telescope, and a transit instrument, we undertook to examine the apparent motions of one of the planets,—Mercury, for instance,—in the heavens.

We should very soon perceive that there are certain periods when this planet appears for several successive days not at all to move his place in the heavens; that at other times he moves rapidly forwards, *eastward*, or in the direction of the sun's motion; and that, at other times, he retrogrades for a short space, or moves *westward*, and then returns

again to his forward course. Moreover, that sometimes he moves faster in longitude than the sun, and sometimes slower; so that at one time he *gains* upon him, and at another *is gained* upon by him. Now, in this way, he will be seen, if to the west of the sun, after a time so to have gained upon him as actually to have overtaken him, to have passed him, and to have passed considerably to the east of him, rising before him in the morning, and setting before him in the evening; and thus, being what is called a morning star, he will continue to gain upon the sun, getting further from him to the eastward, for about fifty-eight days, and then the sun will begin to gain upon him, and in fifty-eight days more will have overtaken him, will pass him, and continue to leave him further behind for another fifty-eight days, when the planet will begin to gain on the sun as before.

But let us follow these motions yet more accurately. Suppose that on the 1st of January, Mercury was at one of his stationary points, and his apparent diameter measured by means of the micrometer, and his longitude marked on a chart; on the 10th of January he will have appeared to move forward in longitude through about 7°, the sun having moved somewhat more; and if his apparent diameter be now measured, it will be found to have become considerably less than it was, so that his distance must have become greater; taking, moreover, his first distance from the point supposed to represent the earth's place on the chart, and his present distance, in the inverse ratio of his apparent diameters, and giving him his proper longitude, we shall find his place on our chart at this second period. The 10th of February will find him advanced about forty more degrees eastward; in which time he will have considerably gained upon the sun; and his diameter, if examined, will be found to be still less than at the last observation, so that he must yet further have receded from the earth: his new position will be marked on the chart like the last. This diminution of his apparent diameter, and consequent increase of his actual distance from

the earth, will continue until about the 22nd of February, when it will attain its maximum, and the planet will, in the intervening twelve days, have advanced at least 15°, still gaining on the sun. On the 10th of March the apparent diameter will have diminished to about what it was on the 10th of February, and the planét will have moved, in the intervening twenty-nine days, through about 44° of longitude, greatly gaining, as before, on the sun. The 20th of March will find him advanced 18°, and still rapidly gaining on the sun, and his apparent diameter will have considerably increased: the next eleven days completing the month will only find him advanced 12°, still gaining, however, upon the sun, but greatly less than in the preceding ten days. With this diminution of his motion forward in the direction of the signs, his motion directly towards the earth will, however, be greatly increased, as will be indicated by a rapid increase in his apparent diameter. From the 1st to the 10th of April the planet will only have moved through five degrees of longitude; on the 10th, his apparent diameter will have become again what it was on the 1st of January; and he will appear stationary in the heavens,—that is, stationary in longitude; for a daily and exceedingly rapid variation in his apparent diameter will indicate that he is rapidly approaching the earth. After two or three days, it will be manifest that the planet is now going backward in the heavens, or towards the west, and by the 20th of April he will have retrograded through at least 5°, and his apparent diameter will then be the greatest: this retrogradation will continue until about the 28th, when he will, on the whole, have retrograded through from 9° 22′ to 15° 44′. Between the 20th and 28th his apparent diameter will have diminished, precisely in the same order and proportion in which it increased from the 10th to the 20th. After the 28th, having appeared stationary for a few days, he will begin to advance, and will go through precisely the same changes as he commenced on the 1st of January.



The planet was gaining upon the sun from about the end of January to the end of March. During this period he will have passed from his greatest distance westward of the sun, to his greatest distance eastward, and will thus have passed him in longitude, or at some intervening time had the same longitude with it; he is then said to be in conjunction with the sun.

If the places of the planet at a long series of different times be marked on our chart as described above, and the points joined, the line joining them will be the actual path of the planet in respect to the earth, and it will be a curve, called an EPICYCLE accurately,* like that traced in the foregoing

* The curve in the figure is copied from one given in FERGUSSON's *Astronomy*, which he traced by means of an orrery, accurately representing the relative motions of the earth and Mercury.

figure, having a series of loops, which mark its stationary points and periods of retrogradation in longitude.

Also, if similar observations be made with respect to Venus, an analogous Epicyclical path, with less frequent loops, will be found.

## LIV.

### The Real Motions of the Planets.

Now, *these motions of Mercury and Venus in respect to the earth, and the positions which at stated times they occupy, are exactly the same as though they revolved round the sun, the one in* $87^{d}{\cdot}969$, *the other in* $224^{d}{\cdot}700$, *and that the sun revolved with them round the earth.* That compound motion being one which would cause them to describe the Epicyclical paths which they actually appear to describe. Moreover, if the motions of the other, called superior, planets be observed, and their paths similarly traced, the result will be the same. Thus the system of Tycho showed a profound acquaintance with the actual motions of the heavenly bodies, and a most careful and accurate comparison of them.

But it will at once strike the reader that these motions of the planets in respect to the earth, on the hypothesis that, revolving round the sun, they, together with the sun, revolve round the earth, are precisely the same as they would be on the opposite hypothesis, that, everything else remaining the same, the sun did not revolve round the earth, but the earth about the sun.

It is a known principle of motion, to which reference has before been made, that if there be any number of bodies moving in any way in respect to one another, and if to each there be communicated the same velocity, all the velocities thus communicated being parallel to one another, and in the same direction, then, whatever may be the *actual* motions of the bodies after these new velocities are communicated to

them, their *relative* motions will be precisely the same as they were before; that is, after the same times they will be at precisely the same real and angular distances as they were before; and thus the relative positions of all the rest, as seen from any one of them, will appear precisely the same on both hypotheses. Hence, then, the sun revolving round the earth, and the planets round the sun in any way, if we suppose that to the sun, the earth, and the planets, thus revolving, there be communicated severally *the same* velocities in parallel directions, whatever these may be, the *relative* positions of the sun, earth, moon, and planets, will be precisely the same as before; they will be, after the same times, at the same actual distances from us, and from one another, and in the same positions in the heavens, as before.

Now, let us suppose the velocity thus communicated to them in common to be that with which the sun has been supposed to move, but in an opposite direction.

The earth, which before stood still, will now move with the velocity which the sun before had; and the sun, having now communicated to it a motion equal to that with which it before moved, but in an opposite direction, will stand still,—whilst the planets moving in respect to the sun precisely as they did before, will now, as they did before, revolve continually round him, and in the same times. Thus, then, it appears that the sun will, by the motion thus communicated, be at rest; the earth will revolve round the sun with the velocity the sun had before; and the planets, too, will all revolve round the sun, now at rest, precisely as they did before round the sun in motion. Thus, then, whatever be the relative positions, motions, and appearances of the sun and planets as seen from the earth, on the supposition that the sun, with the planets, revolves round the earth at rest, the same will they be on the supposition that the earth and planets all revolve, each in its particular orbit, round the sun at rest. And conversely, if the earth and planets all do in reality revolve round the sun at rest, the appearances which

they will present, in reference to each other, and as seen from the earth, will be precisely the same as though the earth were at rest, and the sun carried the planets with it in an annual revolution about the earth, causing each to describe about it a looped Epicyclical orbit. *Whatever are the appearances corresponding to the last hypothesis, the same are those corresponding to the first.*

Now we have *shown* the actual appearance of the heavens to correspond with the *last* hypothesis: they correspond, therefore, to the *first*,—that is, they are the same as they would be if the sun were at rest, and the earth and planets each revolved, in its particular orbit, round him. *And these are the only two hypotheses which can possibly explain the appearances in question.* Also, the hypothesis that the earth is at rest in the centre of the system has, in a preceding paper, been shown to be false. *It follows, therefore, that the other hypothesis*—THAT OF THE QUIESCENCE OF THE SUN IN THE MIDST OF OUR SYSTEM OF PLANETS, AND THE REGULAR REVOLUTION OF OUR EARTH WITH THE REST OF THE PLANETS ABOUT HIM, AS A COMMON CENTRE,—IS THE TRUE HYPOTHESIS, AND THAT IT CONSTITUTES THE REAL SYSTEM OF THE UNIVERSE.

## LV.

### The Stationary Points and Retrograde Motions of the Planets.

Since the apparent motions of the planet in respect to the earth are those represented by the looped line in the figure on page 157, it is manifest that there are certain periods, when, being at any of these loops in its apparent orbit, its motion is in a contrary direction from that which is its *general* tendency. At those periods it is said to *retrograde*. Moreover, that there are certain periods of its motion in each of these loops, when it is not moving at all in the *general*

direction of its motion or the contrary, neither to the east nor the west, but directly *towards* or *from* the earth; so that although at these periods it rapidly alters its magnitude and brightness, by reason of the variation in its distance, yet it does not at all alter its position in the heavens. Under these circumstances, it is said to be at its *stationary* point.

The following are the arcs through which the planets severally retrograde:

| | | |
|---|---|---|
| Mercury, from . . . . | 9°22′ to 15°44′ |
| Venus „ . . . . | 14 35 — 17 12 |
| Mars „ . . . . | 10 6 — 19 35 |
| Jupiter „ . . . . | 9 51 — 9 59 |
| Saturn „ . . . . | 6 41 — 6 55 |
| Uranus „ . . . . | 3 36 |

## LVI.

### THE SYNODIC REVOLUTIONS OF THE PLANETS.

The synodic revolution of a planet, is the time of its returning from any position in respect to the earth into that position again. It is evident that since the periodic time of the earth is different from that of each of the other planets, each is perpetually altering its position in respect to it, one of the two gaining perpetually in longitude upon the other. Moreover, it is evident that the same relative positions in longitude will be a second time attained, or the two will have completed a synodic revolution, when one has thus gained a space equal to 360° upon the other, or some multiple of 360°; for whatever was the angular space which before separated them, it will now be 360° added to that space, or some multiple of 360° added to it; that is, as measured on the circle,—it will be the *same* separation.

Now, we may readily calculate, under these circumstances, what are their mean synodic motions. Let us take their mean daily motions in longitude, and subtract them from one

another. We shall then have their *relative* daily motion, or the daily gain of one on the other in longitude. All that we want, then, is to know how many of these daily relative motions will make up 360° of relative motion, or 360° of gain, of one on the other in longitude; and this is done at once, by dividing 360° by this difference.*

The sidereal and synodic times of the planets, or the times after which they return into the same positions in respect to the earth, are as follows:

| | Sidereal time. Days. | Synodic time. Days. |
|---|---|---|
| Mercury | 87·969 | 115·8774 |
| Venus | 224·7 | 583·9209 |
| Earth | 365·256 | |
| Mars | 686·979 | 779·9364 |
| Jupiter | 4332·584 | 398·8846 |
| Saturn | 10759·219 | 178·0919 |
| Uranus | 30686·820 | 369·6563 |

## LVII.

### The Periods after which any of the Planets will return to the same relative Positions.

Not only can we, however, thus find the time after which any two planets will occupy the same relative positions, but

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* The following very simple algebraical formula determines the synodic time in terms of the periodic times. Let A and B be the periodic times of any two planets in days, then are $\frac{360}{A}$ and $\frac{360}{B}$ their mean daily motions, and $\frac{360}{A} - \frac{360}{B}$ is their relative daily motion. Let S be their synodic time in days, or the number of days in which they separate from one another in longitude through 360; $\therefore$ $\frac{360}{S}$ is their daily separation or relative motion.

$$\therefore \frac{360}{S} = \frac{360}{A} - \frac{360}{B}; \therefore \frac{1}{S} = \frac{1}{A} - \frac{1}{B}, \text{ and } S = \frac{AB}{B-A}.$$

we can extend this method of computation to three or four, or, indeed, to the whole number. It would be possible to tell when all the planets would occupy the same relative positions as at the present time. It has, indeed, been calculated by Laplace, that the common synodic time of the six great planets is 17,000 millions of years. The manner of this computation will easily be understood from one case of its application.

Suppose it were required to find when the Earth, Venus, and Jupiter, would occupy again the same relative positions as at the present moment. The synodic period of Venus and the Earth is $583^{d}\cdot 9$. We know, then, that after this period, or any complete number of times this period, Venus and the Earth will be in the same positions, relatively, as now. Moreover, the synodic period of the Earth and Jupiter is $398^{d}\cdot 9$. So that Jupiter and the Earth will be in the same relative positions as now after any complete number of times *this* period. If, then, we can find any two numbers such that the synodic time of Venus being multiplied by the one, shall equal the synodic time of Jupiter multiplied by the other, we know that after the number of days represented by either of these products, Venus will be in the same position in respect to the earth as it is now, and the Earth will be in the same position in respect to Jupiter,—that is, all three will be in the same relative positions as at the present moment. This process is, in point of fact, that of finding a common multiple of the two numbers. Any such common multiple will give the time after which the phenomenon will return,—the least will give the *first* time. The calculation of these matters formed an important feature in the labours of astrologers, and many wonderful things were believed by them of their relation to the affairs of men and the destinies of empires.

## LVIII.

### Conjunctions of the Planets.

Of all the relative positions of the planets, their conjunctions were believed to be pregnant with the *most* important consequence in human transactions. When two planets have the same longitude, they are said to be in conjunction. The time of such a conjunction is readily found. Suppose the present longitude of two of the planets to be known; their difference will be the angular space which one will have to gain on the other before such a conjunction can take place. Now, subtracting their daily motions in longitude from each other, we know how much they gain daily. We can, therefore, at once tell how many days it will take to gain the whole existing difference of longitude, and thus bring the planets actually in conjunction. The same sort of calculation may be extended to the conjunction of any number of planets.

It is said that a conjunction of five planets took place, and was observed in China, in the year 2500 B.C. There was another, of which we have authentic record, A.D. 1186: it took place between the wheat-ear of the Virgin and $\alpha$ Libræ. Great disasters were predicted as the consequence of this conjunction—belied by the result.

Kepler remarked, that in 748 of Rome, Jupiter, Mars, and Saturn, were in Pisces in February and March, and that in April and May, Venus and Mercury were in conjunction with the sun; and from these facts he concluded, on astrological principles, that our Saviour's birth took place in that year. Such was the weakness of one of the greatest men who have ever devoted themselves to science.

It must, however, be admitted in favour of planetary influences, that at the moment when the cannon were announcing to the people of Paris the peace of 1801, the Moon,

Jupiter, and Venus, were in conjunction somewhere near the heart of the Lion.

Laplace calculated the secular periods of Jupiter and Saturn from a conjunction of these planets observed by an Arab astronomer on the 30th of October, 1007.

## LIX.

### The Inclinations of the Planes of the Orbits of the Planets.

The *apparent* motions of the planets have been described to be the same as though they revolved, each uniformly in a circle, round the central sun; and the sun, together with them, were carried perpetually in a circular orbit round the earth; moreover all these circular orbits have been spoken of as described in the same plane in which the apparent motion of the sun takes place.

Their motions have not thus been *accurately* described. Although, to a first examination, it might appear that their orbits about the sun were circular, and their motions uniform; yet, on a closer inspection, it would be manifest that this mode of describing them requires considerable modification to make it accurately agree with observation. The apparent paths are not, in fact, the same as they would be if each planet moved in a circle round the sun, but in an ellipse; and, moreover, they are not the same as though, together with the sun, they were swept continually in a circle about the earth, but in an ellipse, having the earth in one of its foci; so that, when we come to correct the apparent and complicated system of the universe, by communicating to all the bodies which compose it, the apparent motion of the sun, in an opposite direction, and thus pass to the true hypothesis, —of one central sun at rest, and a system of planets, of which our earth is one, revolving all in the same direction round it,—we obtain for the orbit of each, not a circle, but an ellipse, having the sun in its focus.

Again, instead of supposing them all to revolve in orbits whose planes coincide with the plane of the sun's apparent revolution, or the ecliptic, we shall find, on closer inspection, that they all, more or less, deviate from it. There is not, however, one of the seven greater planets, the inclination of the plane of whose orbit to that of the earth exceeds 7°, and only one whose inclination exceeds half this quantity.

The inclinations of the planets are as follows:—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mercury . . . . | 7° | 0′ | 9″ | Ceres . . . . . | 10° | 37′ | 26″ |
| Venus . . . . . | 3 | 23 | 28 | Pallas . . . . | 34 | 34 | 55 |
| Mars . . . . . | 1 | 51 | 6 | Jupiter . . . . | 1 | 18 | 51 |
| Vesta . . . . . | 7 | 8 | 9 | Saturn . . . . | 2 | 29 | 35 |
| Juno . . . . . | 13 | 4 | | Uranus . . . . | 0 | 46 | 28 |

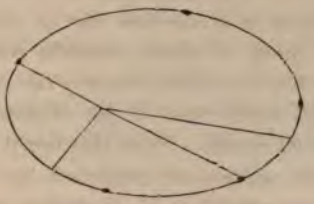
In all these orbits there is a slight secular variation, of which that of Jupiter is the greatest, being 22″·6, and that of Mars the least, being only 0″·1523.

## LX.

### Kepler's Laws.

That remarkable law by which the motion of the earth in its elliptic orbit is governed, which law is called that of the equal description of areas, has been before somewhat fully explained. Now, precisely, the same law is found to obtain in respect to the motions of the other planets in their orbits. The area swept over by a line drawn from the sun to any one of them in a given time, say a month, is always the same, through whatever part of its orbit the motion of the planet may during that month take place; although this line varies in length daily, yet, whether it be longer or shorter, does the planet so regulate its motions, as always to cause it to sweep over the same area in the same time. This law, then, of the equal description of areas, is common to all the

planets, and may well be supposed, as it was when first discovered, to result from some principle of motion common to



all. The discovery of the principle of motion whence it resulted was the first invention of Newton; the proof of it is the first proposition of his *Principia:* it was his first step of approach to the theory of the universe. It results entirely from the fact that the motion of each planet sprung from one original impulse, of which the whole effect remains, combined with the continual attraction of a single centre of force. It has nothing to do with the law according to which that attraction is exerted.

By Kepler's second law, each planet describes an *ellipse*, in one of whose foci is the sun. This, again, is a law deducible from the same principles, provided that the particular law which governs the attractive force of the sun is that of the inverse square, as it is termed; or, in other words, provided that it is such as to be equal to a certain quantity, the same at every distance, divided by the square of the distance. Since, then, this elliptic form of the orbit is a necessary consequence of that particular law of attraction, and that it could not obtain if the law of attraction were any other, it follows that the law of attraction *is* that of the inverse squares. The nature of this law of attraction may, perhaps, be better understood thus; if we conceive a number of equal particles to be situated at different distances, then will the attraction of the sun upon them be such, that each attraction being multiplied by the square of the corresponding distance, all the products will be the same.

Not only, however, does there exist a relation between the motions of the same planet in different parts of its orbit, but the motions of the different planets in their several orbits are further subject to a common law or relation, which is this,—that the times of their complete revolutions, being squared, will be found to have precisely the same ratio to one another that the major axes of the ellipses in which they revolve have when cubed. From this law it follows that the motions of all the planets are controlled, by the *same* energy residing in the sun, modified in its action upon each planet only by the distance of that planet.

The laws of which we have spoken are called those of Kepler: they were discovered by him before the theory of gravitation had been developed by Newton: they are the experimental, or, rather, the observed facts, on which the whole of that theory is based, and without which it might probably have been imagined, but could not have been demonstrated.

But the discovery of these laws necessarily supposes an accurate knowledge of the actual and real motions of each planet in its orbit, continued from day to day, and through a long period. Now it has been shown that their actual motions are prodigiously different from their apparent motions. These last are of the most complicated kind; each planet moves apparently in an orbit whose appearance is that of a scroll, looped or zigzag, and although this curve is governed, indeed, by a geometrical law, being of the nature of an hypocycloid, or, rather, an hypo-ellipsoid, yet is that law of so complicated a kind, that the separation of the true from the apparent motion of a planet by means of it, would seem to be nearly an impossibility.

This is not, however, the method of ascertaining the true motion of a planet about the sun, or as seen from the sun, which is actually in use among astronomers. That method is but an approximation; it is, nevertheless, attended

with such difficulties, as to place it beyond the reach of a popular explanation.*

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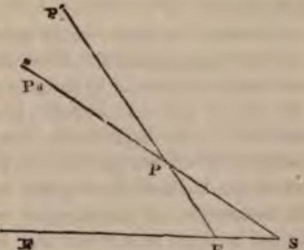
* THE GEOCENTRIC AND HELIOCENTRIC PLACES OF THE PLANETS.

In the first place, there is an important difference between the position which a planet appears to occupy when seen from the earth, and the position which it would appear to occupy, if seen at the same instant from the sun.

Let S be the sun, E the earth, at any time, and P the position of a planet at the same instant. Join E P, and suppose it to be produced to the region of the fixed stars, then will P be seen in the sphere of the heavens at P′ by an observer, on the earth at E. But an observer from the sun would see it in the direction of the line S P, at a point P″, differing from P′ by a space in the heavens dependent upon the magnitude of the angle, P′ P P″. P′ is called the geocentric place of the planet, and P″ its heliocentric place. The accurate determination of the heliocentric from the geocentric place, is one of the most difficult problems in astronomy. Could we but determine, at any instant, the actual distance of the planet from the earth, this difficulty would, however, in a great measure, be removed. If we knew the side E P,




of the triangle S P E, knowing its side E S, which is the distance of the earth from the sun, and observing the angle S E P, the angular elongation of the planet from the sun, we should at once, by the known methods of trigonometry, be able to determine the angle F S P.

If the planet moved in the plane in which the earth moves, this angle would at once fix its position; for, knowing the position of the earth, we should have only to measure off this angle from it on the ecliptic, and at once fix the position of the planet. But no planet moves exactly in the same plane as the earth. The line E P joining any positions of the earth and planet is not, therefore, in the plane of the ecliptic, and the angle F S P is not in that plane, except at the time when the planet is in one of the points (called nodes) in which its orbit intersects the plane of the ecliptic. Moreover, the actual deter-

## LXI.

### The Phases of the Planets.

Those planets whose orbits lie without that of the earth are called superior planets, and those whose orbits are within it, inferior planets. Being all of them opaque, spherical bodies, one hemisphere only of them can at any time be enlightened by the sun—viz., that hemisphere which is turned towards him. Moreover, since only one hemisphere of each

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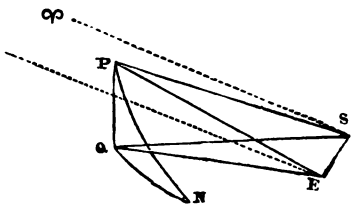
mination of the distance E P of the planet (by method of parallax), is by no means an easy operation, perhaps, indeed, a scarcely practicable one.

The method most readily practised, is not that of a direct deduction of the heliocentric from the geocentric place, but a method according to which an hypothesis is made with respect to the planet's real motion and heliocentric place, and thence its geocentric place deduced. This result being then compared with actual observation, (which is, of course, geocentric), a sufficient number of times, presents the means of determining the hypothetical quantities introduced in the calculation, of ascertaining whether the law of the heliocentric motion is really that which has been supposed, and of fixing all the elements of the orbit.




Let P be supposed to be the place of the planet, E that of the earth, and S that of the sun; also, let S Q E be the plane of the ecliptic, and P Q a perpendicular upon it from P; join Q E and Q S. And let it be supposed that the planet describes an ellipse about the sun, whose half-axes are

can at any time be turned towards the *earth*, if they were even illuminated as to every part of the surface of each, but one hemisphere of any planet could at any time be visible.

Now, if the hemisphere on which we look, when we look at a planet, coincided always with its illuminated hemisphere, it is evident that the whole of that illuminated hemisphere would always be seen; but this is not the case. The hemisphere of the planet towards which we look, when we look at it, does not always coincide with that hemisphere which is

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$a$ and $b$, and that it was in a known part of this orbit, its aphelion, for instance, at a time T, and has for its periodic time P. Now, from these hypothetical data we can calculate, precisely in the same way as for the earth, its actual position in its orbit, at any time when we propose to make our observation, or the angle which it makes with its aphelion distance at that time, and the equation expressing this will involve the quantities $a$, $b$, T, P. Let I be the inclination of its plane to that of the ecliptic, we can thence find what is the above-mentioned angle, reduced to the plane of the ecliptic: and this is the difference of the longitude of the aphelion and planet; and, moreover, supposing L to be the longitude of the aphelion, we may from thence at once find, by addition or subtraction, the actual heliocentric longitude of the planet, in terms of $a$, $b$, T, I, L, which is, if ♈ represent the point Aries, equal to the angle ♈ S Q. Moreover, knowing the angle ♈ E S, which is the sun's longitude, and, therefore, its supplement ♈ S E, and knowing ♈ S Q, we know the angle E S Q; also from the hypothesis of an elliptical motion in a known orbit, we can find the radius vector S P of the planet at P; and if we suppose N to be the longitude of the node, having already found the heliocentric longitude of the planet, we can find at once the difference of longitude N Q, between the planet and its node, and thence, from the supposed inclination, P N Q, we can find P Q. In the right-angled triangle P S Q, we know, then, S P and Q P, and thence we know S Q; and in the triangle S E Q, knowing S E and S Q, and the angle E S Q, we know the angle S E Q, and the distance E Q, called the curtate distance of the planet. And knowing E Q and P Q, we can find in the right-angled triangle P Q E the angle P E Q. Thus, then, we find the angles P E Q and S E Q in terms of $a$, $b$, T, I, N, L.

Now, P E Q is the geocentric latitude which may be *observed*, and

turned towards the sun, and enlightened by him; so that there is not any single planet of which we can see, except at particular times, the whole disc. In respect to the portion of the disc thus rendered, under certain circumstances, invisible, there is a great difference between the superior and inferior planets. The former, being considerably further from the sun than the earth is, have always a considerable portion, indeed the greater portion, of their enlightened sides turned towards us, whilst the latter sometimes present only their unenlightened hemispheres, and sometimes the whole of their enlightened hemispheres, to the earth, and their discs pass,

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S E Q is equal to the sum of Q E ♈ and S E ♈, of which the latter is the heliocentric longitude, known in terms of the same quantities as before, and the former is the geocentric longitude, which may, therefore, be found by the subtraction of the heliocentric longitude from S E Q. Now this geocentric longitude may also be *observed*. Thus, then, the above process will furnish us with two results, which may be compared with observation, or two equations, involving the six unknown quantities, $a$, $b$, T, I, N, L.

Three such observations will, therefore, enable us to determine all those six quantities. One of them, however, N, may be determined by actual observation; for when the planet enters its node, the geocentric latitude and the heliocentric latitude both vanish, or it appears to go through its node at the time when it actually does go through it. The longitude of the point where the planet goes through the node, therefore, is equal to the longitude of the node, and may readily be observed. Thus, then, the conclusion drawn with regard to the position of the node may be verified, and will serve as one verification of the whole hypothesis. Moreover, the elements of one planet's orbit being calculated on the hypothesis of elliptical motion, of the existence of Kepler's laws, &c., these will enable us to determine certain elements of any other planet's orbit, simply by observing its periodic time; other geocentric positions may be calculated from these elements, and on the same hypothesis; and these being compared with observation, the verification of the original hypothesis may be carried to any extent. Now this is what has been done, and the planetary theory has thus been absolutely verified.

in the intermediate period, through all those varieties of phase which characterize the changes of the moon.*

## LXII.

### The Planets. — Mercury.

Mercury is an exceedingly small planet; its diameter is not more than two-fifths that of the earth, and his bulk but one-sixteenth, or three times that of the moon; moreover,

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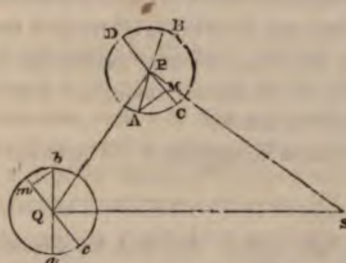
* These appearances will readily be understood by the following diagram.




P and Q are two planets, of which P is the nearer to the sun, S. A C B and *a c b* are the hemispheres turned towards the sun, and, therefore, *enlightened.* A D B and *a d b* are the opposite hemispheres, which are in darkness. C A D is that hemisphere of the planet P, which is turned towards the planet Q, or on which the observer at Q looks, the opposite hemisphere, C B D, being necessarily invisible to him by reason of the opacity of the body. Now, of this hemisphere only A C forms part of the *enlightened* hemisphere; the remainder, therefore, A D, is invisible to him. And if we draw A M perpendicular to C D, D M will represent the greatest width of that portion of the disc which is dark, and C M of that which is light. Now the value of D M depends upon that of the angle D P A, and this last is equal to the angle S P Q. Hence, therefore, it follows, that the thickness of the obscured part depends upon, and varies with, the angle S P Q. But the planet P is, in the course of a synodical revolution, brought into every possible angular position with respect to Q; S P Q goes, therefore, through every possible value between

he is at all times very distant from us, being, when seen under the most favourable circumstances,—that is, when the most of his enlightened hemisphere is towards us,—about as far off as the sun, and when nearest, about three-fifths the distance to him; so that he never appears under an angle of more than 12″, and his apparent diameter is sometimes as little as 5″. Being thus small, and thus remote, he would still be far more distinctly seen than he really is, were it not that he never occupies the dark portion of the heavens, his apparent distance from the sun never exceeding 28° 48′: so that we only see him in that portion of the heavens where the sun has just been setting, or where he is just about to rise; and thus the feeble light reflected by him is scarcely distinguishable, by the naked eye, from the brightness of the sky. Nevertheless, with a telescope, he may readily be found, and thus seen, he appears as he should, being an inferior planet, to have phases like the moon.

After this planet has attained his greatest elongation of

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nothing and two right angles. And thus, the obscured part has every possible width, from nothing to the whole diameter of the circle; this is the case of an *inferior* planet.

Again, let us suppose Q to be looked at from P, the hemisphere on which the observer will look will then be *d b c*, and of this *b* Q *c* will belong to the enlightened, and only *b* Q *d* to the dark side of the planet: so that *b* Q *c* will be the part of it actually seen, and drawing the perpendicular *b m*, *d m* will be the thickness of the obscured part of the disc, and this depends upon the value of the angle *b* Q *d*, being what is called its versed sine; also the angle *b* Q *d* is equal to P Q S. Now the greatest value of the angle P Q S is when the angle Q P S is a right angle, or when Q P touches the orbit of P. Hence, therefore, the width of the obscured part has, in this case, a limit which it never exceeds—viz., that of the versed sine of the angle P Q S, when Q P S is a right angle.

For Mars, the greatest value of the angle P Q S is about 40°, and for Jupiter about 6°, and for Saturn about 5°; taking the versed sines of these angles, we find that the greatest width of the obscured part of the disc of Mars can never exceed one-tenth of the whole, that of Jupiter six-thousandth parts, or that of Saturn, three thousandth parts.

from 16° 12′ to 28° 48′, every day finds him nearer to the sun, until he is lost, even to the telescope, in his beams. In a short time, however, he is discovered again on the opposite side of him, and keeps increasing, in that direction, his distance from him, until a greatest elongation is again, for the second time, attained, and he begins again to approach him, and thus appears continually to oscillate from one side to the other of the sun, as he moves forward in his path.

The duration of each such oscillation is from 106 to 130 days. There are certain periods when Mercury, being in conjunction with the sun, actually passes between him and the eye of the observer. These are called transits over the sun's disc. The centre of the earth being always in the plane of the ecliptic, as well as the centre of the sun, it is evident that this cannot occur unless Mercury also be at the time of its conjunction in that plane, or unless he be then at one of his nodes. Now the nodes of the orbit of Mercury are situated in that part of the ecliptic which the sun passes through in the months of May and November. In order that a transit may take place, Mercury must therefore be in conjunction with the sun in those months. Such conjunctions return every third, fourth, sixth, seventh, tenth, thirteenth year, &c.

Mercury describes an orbit which is greatly more eccentric or elongated than the orbits of any of the other seven great planets, and which is inclined to the plane of the ecliptic at a much greater angle: moreover, he turns (as it is believed) upon an axis which is inclined to the plane of his orbit at a much greater angle than any of the other planets. So that, on the whole, he is *remarkable* among the planets for the great variations of his distance from the sun at different seasons of his year, for the obliquity of his path through space, which diverges widely from the planes of the orbits of all of them, and for the great changes of the temperature of his year, brought about by the great inclination of his axis to the plane of his orbit. The quantity of light and heat which any por-

tion of his surface is at any given time receiving from the sun, is about seven times that which a similar portion of the surface of our earth receives when presented to him at the same angle; and thus the prevailing temperature of a summer on the surface of Mercury may be calculated to be greatly above that at which water boils here.

Mercury is *supposed* to have a dense atmosphere. The force of gravity on the surface of Mercury is somewhat more than three times that of the surface of the earth; so that to lift a mass of equal dimensions and density would require the exertion of three times as much muscular force as here. The mean density of Mercury is, however, only four-fifths that of the earth; so that we may, without any great stretch of imagination, conceive the various objects which present themselves to an inhabitant of that planet to be for the most part specifically lighter than the objects which answer to them here.

## LXIII.

### Venus.

Next to the orbit of Mercury is that of Venus. Venus, although, like Mercury, she never appears but in that quarter of the heavens which the sun has just deserted, or where he is just about to appear, is, nevertheless, one of the brightest and the most beautiful of all the objects visible in the heavens, ranking, indeed, in splendour next to the moon herself. She recedes much further from the sun than Mercury, her greatest elongation being from 45° to 47°; by which quantity she sometimes precedes, and sometimes follows him, being from three to four hours visible in the morning before him, or in the evening after him. The star which thus appears at one time before the sun in the east, and at another after him in the west, the ancients imagined to be not one star, but two stars; they called it, when a morning star, *Lucifer*,

or Phosphorus, Φωσφορος, the star that brings with it the day-light ;* and the evening-star they called *Hesperus*, Ἕσπερος.

The brightness of Venus, as seen from the earth, depends upon two causes; first, upon the shortness of her distance from the earth; and, secondly, upon the greater or less magnitude of that portion of her enlightened hemisphere which is turned towards it. These two causes conspire to render her brightness the greatest twice in each synodic revolution, when her elongation is about 40°. She may then be seen in broad daylight. The appearance of Venus through the telescope is exceedingly beautiful; when brightest, she presents at one time to the eye a small, but beautifully-defined and bright crescent; at another she is a half moon in miniature, and then she becomes gibbous, until, when about to present the appearance of a full orb and a completed disc, she is lost in the sun's rays. Her disc is, for the most part, of unsullied whiteness: spots have, nevertheless, occasionally been seen; and from what is believed to be a motion of these, she is asserted to turn round an axis inclined at an angle of 18° to the plane of her orbit, in a period of $23^h\ 21'\ 7''$. Moreover, it is asserted that certain appearances have been observed about the horns of this planet, indicating the existence of mountains of very great height, four times as high as the mountains on the earth's surface.

It is a very probable hypothesis, that the spots which are seen occasionally to float as it were in the dazzling brightness of this planet's disc, are in reality clouds, buoyed up in a dense atmosphere surrounding the planet, as our atmosphere does our earth; and that, in reality, the light by which we see this planet is not reflected by its solid mass, but by its atmosphere; so that, when we look at it, we see not the planet, but only the air that surrounds it, and in which float clouds, serving to break the intense glare of its sunshine

* Phosphore redde diem.—MARTIAL.

The apparent diameter of Venus varies, according to its position in reference to the earth, from $9''\cdot6$ to $61''\cdot02$.

The diameter of Venus is nearly equal to that of our earth, and in volume she is only one-ninth less than it. Her mean distance from the sun is about five-sevenths that of our earth. She receives twice as much light and heat as our earth from him. The orbit of Venus is an ellipse, much more nearly approaching to a circle than the orbit of our earth, its eccentricity being only about one-tenth that of the earth.

## LXIV.

### The Transit of Venus over the Sun's Disc.

The plane of this orbit is inclined at about 3° 23′ to that of the earth, and cuts it in a line, through which the sun passes in the months of June and December, the longitude of the nodes of Venus being 255° and 75°. Venus returns from any position in regard to the sun, to the same position again, or completes a synodic revolution in 584 days, and during the period of that revolution she moves actually forward in her orbit through 316°, and thus in five synodic revolutions, which she completes in 5×584 days, or 2920 days, she has described 5×216° or 1080° of longitude. Now, 2920 days are equal exactly to eight years of 365 days each, and 1080° are equal precisely to three times the complete circumference of a circle. Therefore, after eight years of 365 days, Venus always returns to the same place in her orbit, and to the same position in reference to the sun. Now, if Venus had an inferior conjunction with the sun when exactly in her node, she would manifestly interpose between the earth and sun, and to an observer at the earth's centre, or to one on the earth's surface, if situated in a line joining the centre of Venus and the sun, she would necessarily appear to pass over the sun's disc: moreover, this

phenomenon may manifestly present itself to an observer situated elsewhere, and even when Venus is not precisely in her node. Its occurrence under these circumstances will manifestly be dependent upon the distance of Venus from the earth and sun; and it serves to determine that distance. Under each variation of these circumstances, the apparent path of Venus across the sun's disc is different; under the most favourable circumstances the transit might last $7^h\ 54'$.

If Venus and the earth described circles, and they both moved uniformly in their orbits, with the mean velocities which we have supposed,—since they would be in the same relative positions after every period of eight years of 365 days, and since in that same period, Venus would have returned to precisely the same place in her orbit,—it is evident that, a transit having at any time occurred, it would, after the space of eight such years, necessarily be followed by another under precisely the same circumstances, and so after the next eight years; and thus the transit of 1761 would be followed by another in 1769, a third in 1777, and so on; and one would have occurred in 1833. Now this is not the case: the transit of 1761 was indeed followed by one in 1769, but there will be no other until the 8th of December, 1874, and this will be followed by one on the 6th of December, 1882. This is easily explained:—neither the earth nor Venus move in reality with their mean or uniform motion; so that they do not in reality return into the same relative positions, after what we have supposed to be the period of a synodic revolution: nevertheless, the deviation is not so great as to bring them without the limits of a transit in one period of eight years, so that, in point of fact, we may always expect the return of a transit in eight years after it has once taken place.

The force of gravity on the earth's surface is only one-third of that on the surface of Venus; so that, if transported to that planet, we should almost be crushed by the weight of our own bodies, and three times the muscular force would be

required to lift the same mass. The density of Venus is very nearly that of our earth.

Next in order is our Earth, of which we have already spoken, and of the circumstances of whose motion round the sun, and the form of its orbit, we know scarcely more than we know of the other planets.

## LXV.

### Mars.

Beyond the orbit of the earth is that of Mars. The mean distance of this planet from the sun is about once and a-half that of the earth, or, when nearest us, he is about half as far from us as we are from the sun. He receives about four-ninths the light and heat from the sun that we do; his diameter is about a half, and his volume is scarcely one-eighth that of the earth, or about six times that of the moon. His orbit is much more eccentric (nearly six times) than that of the earth, and he completes it in a period nearly double that of the earth: the length of his year is $686^d\ 23^h\ 30'\ 41''.4$; his plane of revolution is inclined to that of the ecliptic at an angle of not more than $1°\ 51'$, and his synodic revolution occupies 780 days.

Varying in his distance from the earth, through a space equal to the whole diameter of the earth's orbit, which is more than two-thirds his greatest distance, and twice his least, he varies also very greatly in apparent magnitude. Moreover, presenting sometimes the whole of his enlightened hemisphere to the earth, and sometimes only part, he varies also greatly in apparent brightness. He is at once most bright, as far as this cause affects his brightness, and nearest to us, when he is in opposition to the sun, being then distant from us not more than half the distance of the sun, and appearing under an angle of about 18′; his least apparent diameter is 4″; his oppositions occur after two years and

fifty days. In the month of August, 1719, this planet was in opposition, and at the same time in his perihelion, and his brightness was, under these favourable circumstances, so great, as to give rise to a superstitious terror.

The force of gravity on the surface of Mars is about one-tenth greater than that on the surface of the earth, but his density is greatly less,—almost in the ratio of one to ten. His day is nearly of the same length as ours, being $24^h\ 39'\ 21''$, and the axis about which he turns is inclined at an angle to the ecliptic, which is only 6° different from that of our earth; so that the distribution of temperature on his surface, and the variations of his seasons, are nearly the same as ours, except that each season is of twice the length, whilst the intensity of the sun's rays is not at any time more than four-ninths.

According to Sir John Herschel,* the outlines of what may be continents and seas are frequently to be discerned in this planet. Those portions supposed to be continents are distinguished by that ruddy colour which characterizes the light of the planet, and may be similar to that which the red sandstone districts of the earth offer to an inhabitant of Mars, only more decided, and in contrast with these, by a general law of optics, the seas appear greenish.

## LXVI.

### Ceres, Pallas, Juno, Vesta, Astræa, Hebe, Iris, Flora, Metis, Hygeia.

Next to the orbit of Mars, we find the orbits of ten smaller planets,—Ceres, Pallas, Juno, Vesta, Astræa, Hebe, Iris, Flora, Metis, Hygeia. The dimensions of the orbits of these are nearly the same, but their inclinations to the plane of the ecliptic are greatly different from one another, and from those of the other planets, varying from 5° 28′ to

* "Outlines of Astronomy," p. 312.

34° 37′. Their periods are, Ceres 1681·3 days, Pallas 1686·5 days, Juno 1592·6 days, Vesta 1325·7 days, Astræa 1511 days, Hebe 1379·9 days, Iris 1341·6 days, Flora 1193·2 days, Metis 1345·8 days, Hygeia 2075 days.

The mean semi-diameters of their orbits are—

| | | |
|---|---|---|
| Ceres | . 2·767245 | mean radii of the earth's orbit. |
| Pallas | . 2·772886 | „ |
| Juno | . 2·669009 | „ |
| Vesta | . 2·36787 | „ |
| Astræa | . 2·577047 | „ |
| Hebe | . 2·425786 | „ |
| Iris . | . 2·308624 | „ |
| Flora | . 2·201687 | „ |
| Metis | . 2·385607 | „ |
| Hygeia | . 3·1837 | „ |

The dimensions of all these planets are comparatively insignificant. So small are they, that they are undistinguishable to the naked eye, and their apparent diameters have never been measured with any tolerable accuracy, even with the aid of the most powerful telescopes. It is said, nevertheless, that the largest of them, Juno, cannot have a real diameter of more than 100 miles, or $\frac{1}{80}$th that of the earth. If this be the case, her surface is only the $\frac{1}{6400}$th that of the earth, and her bulk the $\frac{1}{513000}$th part. All these planets have been discovered during the present century, and the last five in the list, since the year 1845.

## LXVII.

### Jupiter.

Next in order to the orbits of these four smaller planets is that of Jupiter, the largest of all the planets. He is 1281 times greater in bulk than the earth, but his mean density is little more than one-fourth that of the earth; so that the

quantity of matter actually contained in his bulk is not greater than that in the earth, in the same proportion in which his volume is greater: it is only about 331 times that of the earth.

The force of gravity on the surface of Jupiter is about eight times as great as that on the earth's surface; so that, standing on the surface of Jupiter, an inhabitant of our earth would have to bear up under a load eight times greater than the weight which he here sustains; and if he walked, he would have to carry eight times the present burden of his body,—eight times the muscular effort would be required to lift and to move any of the objects around him, that is here required for the same purpose; if he leaped, he could, with the same effort, leap only one-eighth the distance; and if he fell, he would fall with eight times the force. The distance of Jupiter from the sun is about $5\frac{1}{5}$th that of the earth; so that the sun's diameter there will appear only the $5\frac{1}{5}$th part of what it does here, and his area about $\frac{1}{27}$th, thus supplying to any given portion of the surface of Jupiter only $\frac{1}{37}$th the light and heat which the same portion of surface here receives. To compensate, however, for this deficiency of heat, every portion of the surface of Jupiter is, in each of his revolutions, brought under the influence of the sun again, after a much shorter interval than here elapses between one noon and another. Jupiter completes a revolution of his huge bulk upon an axis within himself once in every $9^h\ 55'\ 49''$; this rapid return of the sun must tend greatly to compensate the deficiency of heat on the surface of Jupiter arising from his distance. Those forms of animal life must, however, be essentially different from ours, whose periods of repose come more than twice as often. Jupiter's year is twelve of ours, and each of his seasons lasts three years. That is, probably, a gigantic vegetation which goes through this toilsome period of change. Again, although Jupiter receives, during his day, but a small portion of the direct light of the sun, yet he has four moons, whose light

must make his night as bright almost as his day. The axis about which he revolves is inclined at 86° 54′ to the ecliptic; so that his equator nearly coincides with the plane of the ecliptic. Very nearly in the same plane are the orbits of his four satellites; the first distant about six of his radii from him, the second nine, the third fifteen, and the fourth twenty-six. The first completes her revolution about him in $1\frac{7}{10}$th day, the second in $3\frac{5}{10}$th days, the third in $7\frac{2}{10}$th days, the fourth in $16\frac{6}{10}$th days. Thus, all appearing to revolve through his heavens nearly in the same path in periods varying between the extremes of from two to seventeen days, the *variety* of their appearances, as seen by an observer, on the surface of Jupiter, must be infinite. To an observer from the earth, there is no more interesting spectacle in the heavens. With a telescope of moderate power, they may be distinctly seen, at one time all arranged in order, and in the same straight line on one side of the planet; at another, distributed partly on one side, and partly on the other, but still in the same straight line. If watched attentively a few hours, they will be seen completely to change their relative positions, and, after a time, some or other of them will pass into the shadow which Jupiter throws behind him from the sun, and become invisible; or it will pass between Jupiter and the sun, and cast behind it a shadow on his surface, moving like a dark spot across his disc. By reason of the rapid revolutions of the satellites, these eclipses and transits return with great frequency. The first satellite is eclipsed every $42^h$ 20′, the second every $85^h$ 18′, the third every $7^d$ $4^h$, and the fourth every 17 days.

By reason of the small inclinations of the orbits of these satellites to the orbit of Jupiter, their eclipses, unlike those of the moon, return at every synodic revolution, except those of the fourth satellite, which is sometimes so far from Jupiter, that although its orbit is but slightly inclined, it yet lies above the shadow of the planet.

The periods of the eclipses of the satellites of Jupiter are given in the *Nautical Almanac*, and other astronomical

calendars, because of their great utility in the determination of the longitude.

Each of these satellites, it is asserted, and with much probability, turns upon an axis within itself, precisely in the time in which it turns round Jupiter; as does the moon in the time in which she revolves round the earth; thus presenting always the same face to the planet. Jupiter's revolution round the sun is completed in $4332^d\ 14^h\ 2'$, or nearly 12 years: his equator nearly coinciding with the plane of his orbit, he can have very little variety of seasons. By reason of his more rapid revolution on his axis, and his greater diameter, it is manifest that the various points of his surface must be carried round much more rapidly in his daily motion than the corresponding points on ours. In point of fact, the velocity of the daily revolution of the equatorial regions of Jupiter is 26 times that of the earth, and the centrifrugal force resulting from this greater velocity, 62 times greater. If, then, the flattening of the earth at its poles result from this cause, a much greater departure from the spherical shape may be expected to be apparent in the form of Jupiter; this, in point of fact, is found to be the case. The equatorial diameter of Jupiter is ascertained, by observation, to be greater by $\frac{1}{14}$th than his polar diameter—a result which coincides with theory.

## LXVIII.

### Saturn.

Next in space to the orbit of Jupiter is that of Saturn. His mean distance from the sun is about $9\frac{1}{4}$ times that of the earth; his diameter 79,042 miles, or about ten times greater than that of the earth: his year is 29 years, 5 months, 14 days of our time in length; he turns upon an axis inclined at an angle of 60° to his orbit, in $10^h\ 29'\ 16''$, and the diameter of the sun appears, as seen from his surface, only to subtend about $3'{\cdot}37$ in the heavens, covering a space of only about $\frac{1}{80}$th that which our sun appears to cover.

Thus Saturn derives from the sun only $\frac{1}{80}$th the light and

heat that we do; the sun, however, returns more than twice as soon to the meridian of any place on his surface, and the deficiency of direct solar light, and, perhaps, heat, is abundantly supplied by the reflected light of seven satellites; and a huge ring of attenuated matter, capable of reflecting the sunlight, girds the planet round his equator like a zone, but is separated from him by a space of at least 70,227 miles; the width of this ring is probably about 30,039 miles; it is, however, double, being composed of two concentric rings in the same plane, of which the larger is the most distant from the planet, and the width given above includes the space between the two. Whilst the ring is, in width, of these enormous dimensions (about one-third of the diameter of the planet), its thickness is so small as scarcely to be discernible. In the midst of this ring, the planet, as seen through a good telescope, appears to repose, presenting, at certain seasons, nearly the whole of the flat portion of it to the spectator; at another, having nothing but its edge turned towards him, and so that its existence is only recognised by the shadow which it casts in a dark line across the planet's disc. All these appearances are governed by the fact, that the plane of the ring, coinciding with that of the planet's equator, remains always parallel to itself. The ring of Saturn revolves with it, and the seven satellites of the planet have all their orbits in the plane of the ring.

"The rings of Saturn," says Sir John Herschel,* "must present a magnificent spectacle to those regions of the planet which lie above their enlightened sides, as vast arches spanning the sky from horizon to horizon, and holding an almost invariable position among the stars. On the other hand, in the regions beneath the dark side, a solar eclipse of fifteen years in duration under their shadow, must afford (to our ideas) an inhospitable asylum to animated beings, ill compensated by the faint light of the satellites. But we shall do wrong to judge of the fitness or unfitness of their condition

* "Outlines of Astronomy," p. 321.

from what we see around us, when, perhaps, the very combinations which convey to our minds only images of horror, may be in reality theatres of the most striking and glorious displays of beneficent contrivance."

## LXIX.

### Uranus.

The most distant of all the planets from the sun is that discovered by our illustrious countryman, Herschel, in the year 1781, and named by him the Georgium Sidus, although it is more commonly called Herschel, or Uranus. Its distance from the sun is more than 19 times that of the earth, and 84 years are occupied in a single revolution through its orbit; its diameter is about 35,000 miles, and its bulk 82 times that of the earth. The sun, as seen from it, has a semi-diameter of not more than 1′ 40″, and its surface appears 400 times less than it appears as seen by us, supplying $\frac{1}{400}$th part only of the light and heat. Its orbit is inclined only 45′ to the ecliptic, and there revolve about it six satellites in orbits nearly perpendicular to its own. It has certainly four satellites, and possibly six. The planes of these satellites are nearly perpendicular to the plane of the planet's orbit, and their motion, as compared with that of the planet itself, and with all the other planets and their satellites, is *retrograde;* that is, they move from east to west, whereas the planet Uranus and all the other planets and their satellites move from west to east.

## LXX.

### Neptune.

When, after the discovery of Uranus in 1781, it came to be carefully observed, and the elements of its orbit had been calculated from these observations,—as was done by M. Bouvard from those made between 1781 and 1820,—it became possible to determine the position of the planet at

any preceding or subsequent period, in accordance with these elements. It having, moreover, been discovered that the planet, although not known to be such until 1781, had been observed as early as 1690 by Flamstead, and its place noted as a star, and, subsequently, on nineteen other occasions, by this and other astronomers, all recording its places under the same false impression, that they saw as many different stars; the means were afforded of testing the truth of these calculations, by comparing the positions in which the planet ought to have been at these times, with the positions in which it had been observed to be. The calculations and the observations were not found to agree, and the discordances were so great, and of such a nature, as to throw great doubt on the accuracy of the calculations; and this doubt was confirmed, when a yet greater discordance was discovered between them and observations made subsequently to 1820. The calculations of M. Bouvard having fully taken into account the perturbations of the motion of Uranus, produced by the attractions of Saturn and Jupiter, which alone, of the planets then known to complete our system, could exercise a sensible influence upon it, it seemed impossible to account for a further disturbance of its orbit, except by supposing it to be subject to the attraction of some other unknown and more distant planet; and this supposition of M. Bouvard was generally entertained by astronomers. About the year 1845, the idea appears to have occurred independently to Mr. Adams, in England, and M. Leverrier, in France, that it might be possible from a knowledge of the disturbance thus produced by this supposed external planet, so far to determine the elements of the orbit of that planet, if any such existed, as might be necessary to fix its place at a given time with accuracy enough to enable observers to *find it*.

"Both succeeded," says Sir J. Herschel,* "and their

* "Outlines of Astronomy," p. 508. The reader will find in that able work a popular account of the nature of these perturbations. The particulars stated in the text have chiefly been collected from it.

solutions, arrived at with perfect independence, and by each in entire ignorance of the other's attempt, were found to agree in a surprising manner, when the nature and difficulty of the problem is considered; the calculations of M. Leverrier assigning for the heliocentric longitude of the disturbing planet on the 23rd September, 1846, 326° 0′—and those of Mr. Adams (brought to the same date) 329° 19′."

"On the day above-mentioned—a day for ever memorable in the annals of science—Dr. Galle, one of the astronomers of the Royal Observatory of Berlin, received a letter from M. Leverrier, announcing to him the result he had arrived at, and requesting him to look for the disturbing planet in or near the place assigned by his calculation. He did so, and on that very night actually found it." Its heliocentric longitude was 326° 52′, which differs but 0 52′ from that assigned to it by M. Leverrier, and but 2° 27′ from that of Mr. Adams.

The periodic time of Neptune is 164·6181 tropical years, and its distance from the sun 30 times that of the earth. One satellite has been discovered by Mr. Lassels, whose orbit is said to be inclined at an angle of 35° to the ecliptic.

TABLE OF THE SOLAR SYSTEM.

| Planet. | Sidereal Period. | Mean Distance from Sun. | Eccentricity. |
|---|---|---|---|
| Mercury ............... | 87d ·9692580 | ·3870981 | ·210551494 |
| Venus ................... | 224 ·7007869 | ·7233316 | ·00686074 |
| Earth ................... | 365 ·2563835 | 1 0000000 | ·01685318 |
| Mars ................... | 689 ·9796458 | 1·5236923 | ·0933070 |
| Vesta ................... | 1325 ·7431 | 2·36787 | ·089130 |
| Juno..................... | 1592 ·6608 | 2·669009 | ·257848 |
| Ceres ................... | 1681 ·3931 | 2·767245 | ·078439 |
| Pallas ................... | 1686 ·5388 | 2·772886 | ·241648 |
| Jupiter.................. | 4332 ·5841212 | 5·202776 | ·0481621 |
| Saturn .................. | 10759 ·2198174 | 9·5387861 | ·0561505 |
| Uranus.................. | 30686 ·8208296 | 19·182390 | ·0466108 |
| Neptune ............... | 60126 ·71 | 30·0368 | ·0087195 |

TABLE OF THE SOLAR SYSTEM—*continued.*

| Planet. | Epoch. | Mean Longitude. | Long. Perihelion. | Long. Ascend. Node. |
|---|---|---|---|---|
| Mercury | 31 Dec. 1800 | 163° 56′ 27″ | 74° 21′ 47″ | 45° 57′ 31″ |
| Venus... | Ditto. | 10 44 35 | 128 37 1 | 74 52 40 |
| Earth... | Ditto. | 100 9 13 | 99 30 5 | |
| Mars ... | Ditto. | 64 7 2 | 332 24 24 | 48 1 28 |
| Vesta ... | Feb. 19, 1854 | 164 26 36 | 250 56 28 | 103 22 50 |
| Juno ... | March 15, 1854 | 143 51 14 | 54 13 13 | 170 56 22 |
| Pallas... | April 13, 1853 | 184 12 25 | 121 26 39 | 172 45 34 |
| Ceres ... | April 25, 1853 | 208 50 43 | 148 19 59 | 80 51 13 |
| Flora ... | Oct. 1, 1850 | 11 48 53 | 32 48 27 | 110 20 13 |
| Iris ... | May 6, 1850 | 243 58 39 | 41 24 10 | 259 42 50 |
| Metis... | June 19, 1850 | 63 52 17 | 71 4 48 | 68 29 22 |
| Hebe ... | April 1, 1850 | 189 45 38 | 15 10 7 | 138 31 38 |
| Astræa .. | Aug. 12, 1848 | 321 38 15 | 135 34 40 | 141 26 13 |
| Hygeia.. | July 14, 1850 | 279 58 6 | 234 25 54 | 287 15 27 |
| Jupiter.. | 31 Dec. 1800 | 112 12 36 | 11 8 35 | 98 25 34 |
| Saturn.. | Ditto. | 135 20 22 | 89 8 58 | 111 35 47 |
| Uranus . | Ditto. | 177 47 18 | 167 21 42 | 72 51 14 |
| Neptune | Jan. 1, 1847 | 328 13 53 | 11 13 41 | 130 5 39 |

| Planet. | Inclination of the Orbit. | Secular Variations of | | |
|---|---|---|---|---|
| | | Long. of Perihel. | Long. of Node. | Inclination. |
| Mercury ... | 7° 0′ 0″ | + 643″ ·56 | − 782″ ·27 | + 18″ ·183 |
| Venus ...... | 3 23 25 | − 267 ·60 | −1869 ·80 | − 4 ·552 |
| Earth ...... | ........... | +1177 ·81 | | |
| Mars ...... | 1 51 0 | +1582 ·43 | −2328 ·44 | − 0 ·152 |
| Vesta ...... | 7 8 9 | unknown. | | |
| Juno ...... | 13 4 45 | | | |
| Ceres ...... | 10 37 26 | 12130 | 148 | 440 |
| Pallas ...... | 34 34 55 | unknown. | .............. | .............. |
| Flora ...... | 5 53 2 | .............. | .............. | .............. |
| Iris ......... | 5 28 16 | .............. | .............. | .............. |
| Metis ...... | 5 35 36 | .............. | .............. | .............. |
| Hebe ...... | 14 46 42 | .............. | .............. | .............. |
| Astræa...... | 5 19 24 | .............. | .............. | .............. |
| Hygeia ... | 3 47 4 | .............. | .............. | .............. |
| Jupiter ... | 1 18 52 | + 663 ·86 | −1577 ·57 | − 22 ·609 |
| Saturn ...... | 2 29 38 | +1943 ·07 | −2266 ·47 | − 15 ·512 |
| Uranus ... | 0 46 25 | + 238 ·62 | −3597 ·96 | + 3 ·153 |
| Neptune ... | 1 47 1 | | | |

NOTE.—The elements of the Asteroids and of Neptune are taken from the *Nautical Almanack* for 1853.

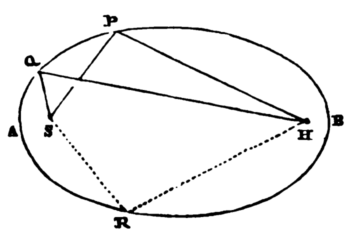
TABLE OF THE SOLAR SYSTEM—*continued.*

| Planet. | Time of Rotation. | Masses. | Volumes. | True Diameters. |
|---|---|---|---|---|
| Sun ......... | $23^d$ $10^h$ | 329630·000 | 1328460·1 | 109·93 |
| Mercury ... | $24^h$ | 0 1627 | ·1 | ·39 |
| Venus ...... | 23 30′ | 9243 | ·9 | ·97 |
| Earth ...... | 23 56 | 1· | 1· | 1· |
| Mars ...... | 24 40 | ·1294 | ·2 | ·56 |
| Jupiter ...... | 9 52 | 308· 940 | 1470·2 | 11·56 |
| Saturn ...... | 10 16 | 93· 271 | 887·3 | 9·61 |
| Uranus...... | unknown. | 1·690 | 77·5 | 4·26 |

## LXXI.

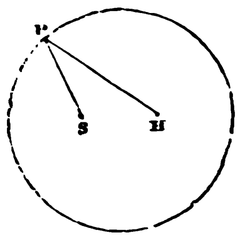
### Properties of the Ellipse connected with the Theory of Comets.

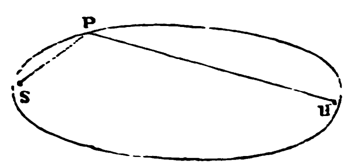
If a fine thread be taken, and its two extremities fastened to two points, S and H, fixed on a flat surface, and not so far distant from one another as the thread is long; and if the thread, which will thus lie loosely between the points, be now stretched by means of a slender pencil to P, and keeping it thus stretched, if the pencil be made to move to Q, tracing as it thus moves a line P Q, that line will form part of a



curve called an ellipse, the whole of which curve may be described by continuing the motion of the pencil completely round in the direction P Q R. Now the lines S P and P H, added together, are equal to the length of the string; for when the pencil was at P, the string coincided with them, and for the same reason, the lines S Q and Q H are, together, equal to the length of the string, and are, therefore, together equal to S P and P H added together; and this is the distinguishing property of the ellipse: "If, from *any* point in it, lines be drawn to S and H, the sum of these will always be the same;" thus at R, the sum of the lines R S and R H is equal to the sum of Q S and Q H, and P S and P H.

If now the point H be brought nearer to S than it was before, the length of the string remaining the same, and the curve be then described, as before, it will be found to have altered its form, so as more nearly to approach that of a circle, as shown in the second figure, and H may be brought so near to S, that its form shall scarcely be distinguishable from that of a circle, which figure it would indeed manifestly become, if the point H were made accurately to coincide with S.




Again, if instead of being moved nearer to S the point H be moved further from it, then the ellipse will be found to have assumed a form like that of the third figure, not nearer to, but further from, the form of a circle than it was at first. Ellipses whose foci S and H are near one another, and which, therefore, approximate to circles, are called ellipses of small

eccentricity. Ellipses whose foci are further from one another, and which, therefore, deviate more from circles, are called ellipses of greater eccentricity. These curves have been supposed to be described with a piece of thread short enough to be conveniently used for the purpose. But curves may be imagined to be described according to the same law, and having, therefore, the same *properties*, traversing vast and inaccessible regions of space, and in which dimensions, which we have taken to be inches, are replaced by millions of miles.

The properties of the ellipse have, even from a very remote period,* been the subject of careful study among geometers, and their acquaintance with them is so far perfected, that knowing certain circumstances with regard to *any portion* of an ellipse, or having certain *data* (as it is termed) in respect to that portion of an ellipse, they can tell the form and magnitude of the whole of the ellipse. Having these data of any, the least part, they know certainly what is the whole of the ellipse of which it forms a part.

## LXXII.

### To Identify a Comet.

Now, *four* observations upon one of the heavenly bodies, describing an ellipse,† are sufficient to give an observer at the earth's surface these data. Thus, then, four observations

* Apollonius Pergæus, the author of a most learned treatise on the curves, called Conic Sections, of which number is the ellipse, flourished in the second century before Christ.

† A comet can only be seen when it is describing that portion of its elongated orbit which is nearest the sun; now this portion of its orbit coincides very nearly with the corresponding portion of a certain other curve, called a parabola, and *three* observations are sufficient on the supposition that it is a parabola.

tell him what is the ellipse, which, if it describe an ellipse, a comet is describing. Now, knowing the *form* and *magnitude* of the ellipse, he can further, by another known process of calculation, tell all the circumstances of the comet's motion in it; and if it really move in an ellipse, he can, therefore, tell beforehand, what place it will occupy in it, after any given time.

Suppose him to have done this, and to wait until that time, and again then to observe it. If his observations agree with the prediction, he will know that he was right in supposing the comet to describe an ellipse—and *that particular ellipse.* Now, observations of this kind have for the last two centuries been made upon all the comets which have appeared, one hundred and thirty in number, and the observations on each have been repeated so as to verify one another in a great variety of different ways; and the conclusion from all has been the same; viz., that those portions of their orbits, which the comets are describing when within our sight, are ellipses;* ellipses which have all of them the sun for their focus, or rather for one of their foci,—and that the other focus is infinitely far off, beyond the limits of the orbit of the most distant of the planets. Moreover, that all these ellipses are of the kind which we have described as of *great eccentricity*, or deviating greatly from circles. Now, similar observations applied to the planets of our system, show them also to describe ellipses, having, too, the sun in one of the foci of each ellipse; but these ellipses are of exceedingly *small eccentricities*, or they approximate very nearly to circles.

But the elliptic orbit of a comet may lie in an infinite variety of positions in respect to the sun, and yet in all these have its focus in the sun. The length of the ellipse may lie one way or another, to the right or the left of a line drawn, for instance, from the sun to a particular star, or at any a

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* This observation will be qualified.

gular distance from that line, or having its plane inclined, at one angle or another, to the plane of the orbit which our earth describes round the sun; and all these things we are required to know, before we can fix what is the precise path in space along which the comet goes. They are called the elements of its orbit. And on the other hand, knowing these, we do know precisely the curved line which through the years, perhaps centuries, of each of its revolution, the comet is describing through the fields of space. Nay, more, we can tell precisely what part of that path it is at any given time describing; the inward eye remains, as it were, fixed upon it, long after it is beyond the reach of the most powerful telescopes. We can tell when it will slowly reach its greatest distance from the sun, or its *aphelion*, as it is called, somewhere, perhaps, double or treble the distance of Uranus from us; and we can tell precisely when it will go through its perihelion, or that extremity of its orbit in which it is nearest to the sun and to us. Now these other elements of a comet's orbit may all be determined from the same four observations which ascertained its form and its magnitude.

These things have been calculated in respect of one hundred and thirty, or one hundred and forty comets, which have appeared at different periods of the two last centuries, and if from this number three or four be excepted, no two will be found to describe the *same orbit*,—no two of them are, then, different returns of the same comet. But if two comets, appearing at different periods, had on examination been found to be describing, one of them at one period the same path in space, which the other did at the other period; if, moreover, the actual motion of the first comet, known from a previous knowledge of its orbit, ought to bring it precisely to that point of its orbit, where the second comet was, at the *time* or near about the time when it was seen there, then we should have known that the two comets were, in fact, *one and the same comet.*

Out of the whole number, there are however *three*, the

identity of which with three others, is established. Of these, one is the comet of 1835, or 1759, called Halley's comet, because he first established its identity with the comet of 1682, 1607, and 1531; another is the comet called, for a similar reason, the comet of Encke, and the third is the comet of Biela; the first has a period of about seventy-six years, the second of three years and three-tenths, and the third of seven years and three-quarters. A comet discovered at Paris by M. Faye, in 1843, has been calculated by M. Nicolai to have a period of somewhat less than seven and a half years. If this comet should return in 1851,* as according to this calculation it ought to do, a fourth will be added to the number of comets whose orbits may be considered to be determined; and a fifth and sixth, if observation should in like manner confirm the calculations made in respect to a comet discovered in 1844 by M. de Vico, and one in 1846 by M. Brorsen, to both of which, periods of about $5\frac{1}{2}$ years are assigned.

## LXXIII.

### The Number of Comets.

Thus, then, we know that there are at least one hundred and thirty *different* comets revolving continually about the sun, that number of different comets *having been seen* during the last two hundred years. None of these, except three have as yet had time to return to us; these three have returned severally at their appointed periods.

How many other comets there may be, or what is the whole number of bodies which compose the *cometary*, as distinguished from the *planetary*, system of our sun, we know not. Comets have been *observed* and calculated by astronomers only during the two last centuries; one hundred

* Passing its perihelion on the 3rd of April.

thirty different ones have during that time been seen, and more are continually discovered, as instruments are perfected and observations multiplied.* Nevertheless, hundreds may, during this period, have escaped observation, because of their distance and the faintness of their light, or because we cannot observe the heavens in the day, and they traverse them so rapidly, that long before the period of the year when that portion of the sky in which they move becomes visible, they are gone.† The comet of Biela could only be found by Sir John Herschel, "with a reflecting telescope of twenty feet in length, an instrument of enormous power in the collection of light." What shall we say, then, of the number and variety of the cometary bodies, which might have been discovered, had we instruments of greater power, were our observations more numerous, and carried back through a greater distance; or what shall we say of the possible number of cometary bodies which may be discovered during the two next centuries? It is quite within the bounds of possibility, that the number of the different comets, revolving continually round the sun, may amount to thousands.

## LXXIV.

### The Positions of the Orbits of the Comets, and the Directions of their Motion.

Those which are known to us have their orbits lying in every conceivable position in space, subject all, however, to the condition, that one of their foci is occupied by the sun. They have their planes inclined to one another, and to the plane of the earth's orbit, at every possible angle up to ninety

* Scarcely a year passes in which one or more new comets are not discovered.

† It is related by Seneca, that during a great solar eclipse, sixty years B.C., a large comet was seen near the sun.

degrees, and the lengths of their orbits are directed towards any and every point in space; moreover, and this is a singular fact, they have the directions of their motions some one way and some another. Thus, one comet revolves in its orbit eastward, and another westward. Moreover, by reason of the elongated forms of their orbits, and their various directions in space, these orbits are made continually to cross one another, and the orbits of the planets and comets are thus frequently brought into such positions, in respect to the planets, that the attraction of these greatly interferes with, and controls, the attraction of the sun upon the comets.

Now, in all these points of view, the cometary is distinguished from the planetary system of the universe. The orbits of the planets are all of exceedingly small eccentricity, they differ little in form from one another, and none of them much from circles. Their planes are none of them inclined much to one another, or to the plane of the earth's orbit.* Their orbits never intersect one another, and their distances are such, that the attraction of the rest upon any one must always be greatly less than the attraction of the sun upon it; moreover, all of them describe their orbits *the same way*, or in the same direction, towards the east.

These differences between the system of the planets and the system of the comets, are not without a reason; they involve another and infinitely important distinction between the two systems.

## LXXV.

### The System of Planets is stable, the System of Comets is unstable.

These are terms which must be explained. All the bodies of our system (and from recent observation it appears

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* The inclination of the orbit of Mercury to that of the earth is greater than that of any other of the seven greater planets, and it does not much exceed seven degrees.

of every other), attract one another, each planet is attracted by every other planet, as well as by the sun, and in reality moves more or less in consequence of, and in obedience to, each such attraction, deflecting more or less, continually, from the path which it would otherwise describe, according to the greater or less proximity of the disturbing body. And the aggregate result of these disturbing motions is, an orbit whose general character is that of an ellipse, but which is not in reality an ellipse; an orbit which, moreover, is continually changing, no two successive orbits of a planet round the sun being exactly the same. This continual alteration in the paths of the planets through space, might go on with more or less of rapidity, and it might be such as in its nature would go on *infinitely*, so that we might be assured that our system should never again be what it now is. Nay, a state of things may be imagined, such as would produce a continual change of this kind, leading necessarily and ultimately to its entire destruction. Now, we are assured by the most certain reasoning, that the state of things which actually exists, is *other* than this—that it is a state of things, which renders it *impossible* that the forms of the planetary orbits should continue to change for ever; that, on the contrary, the existing state of things renders it absolutely certain and necessary, that (if nothing else interfere) eventually, after perhaps millions of years, each planet shall be again describing the very same path that it is now describing, and the whole order of planetary disturbances return from period to period, by almost imperceptible degrees, and in an eternal cycle. This condition of the system is that which is meant by its stability, as the opposite condition is implied by instability.

Now the peculiar circumstances out of which the stability of the planetary system arises, are precisely those in which we have described it, as distinguished from the cometary system. They are the great excess of the attraction of the sun upon any of the bodies which compose it, as

compared with that of any other body; the uniform direction of the revolutions of the planets in their respective orbits, towards the east; the small eccentricities of their orbits, and their small inclinations to one another. From these *provisions* in our system it arises, that it is stable, *and if any one of them* were wanting, it would be unstable. Now in the cometary system, not one of these obtains; it is therefore unstable, and in a state of continual and rapid change, and thence arises the great difficulty of calculating the motions of the comets.

## LXXVI.

### The Tenuity of the Substance of Comets.

The masses of such comets as have been observed are all exceedingly small, indeed it would seem infinitely small,* as compared with those of the planets of our system; so that although they exercise no perceptible influence on the motions of the planets, however near they approach them, yet do the planets exercise a very sensible control over theirs. A comet was discovered in 1770, and its orbit was calculated by Lexel to be described in 5½ years. At the expiration of that period, it was however looked for in vain, and it was called Lexel's *lost comet.* Years afterwards, it was shown by Laplace, that this comet, when returning, had passed so near to Jupiter, that the attraction of that planet upon it had become 200 times as great as the attraction of the sun, and the result was, that the form of its orbit had

* If Halley's comet had been the 20,000th part of the mass of Jupiter, Laplace has calculated that it would have produced an effect on the motions of that planet, which would have been in 1682 distinctly perceptible with our instruments, and in 1835 it would have been perceptible even had the mass of the comet been much less. If the comet of 1770 had been the 5000th part of the mass of the earth, it would have perceptibly lengthened our year.

been so completely altered, that from $5\frac{1}{2}$ years, it came to be an orbit described in 30 years. The attraction of Jupiter upon this erratic comet actually brought it between that planet and his satellites, and yet, so small was its mass,* so wonderful its tenuity, that it produced not the slightest alteration in the motions of any one of them. There is reason to think that the comet discovered in 1843, by M. Faye, may be the lost comet of Lexel. If there be a *resisting medium* in the regions traversed by comets, the greatness of their bulk, and the tenuity of their substance, cannot but subject them in a far greater degree than the planets, to the influence of such a medium. Its effect, paradoxical as this may seem, would be to diminish the time of each successive revolution. Now, this continual diminution of the periodic time is actually taking place in respect to the comet of Encke, under circumstances which it appears impossible in any other way to explain.

## LXXVII.

### The disturbing Attraction of the Planets.

Every comet when it enters our system has its orbit more or less changed by the influence of the planets, and in some cases that influence is felt throughout the whole of the comet's course. Thus, the comet of 1835, never, throughout the whole of its course, extending three billions of miles from the sun, escaped the sensible attraction of Jupiter.

Thus, then, it appears, that those changes which, in respect to the orbits of the planets, are necessarily, and must ever be *gradual*, and almost imperceptible, are, as it regards

* A distinction must be made by the reader between mass and dimensions: mass has reference only to the quantity of matter; and thus a body may have a very small mass, and yet very great dimensions: this is the case with the comets.

the orbits of the comets, not only perceptible, but remarkable, and moreover that, whereas the changes of the planetary orbits must return in certain cyclical periods for ever, those of the cometary orbits will not; so that what the cometary system is at any given time, it can never (that is, it cannot except by an infinite improbability) be again: but to what this perpetual series of changes tends, or in what it will terminate, no one has, probably, been bold enough to make the subject of his speculations.

Enough has been said to show that the calculation of the motions of the comet is no easy matter. The attractions of five bodies, all of which, except one, are continually moving upon another, which is itself also perpetually in motion,—these attractions, each of them varying, with each change of distance, their effects in accelerating or retarding the attracted body, or in altering the path which it has described, —effects to be considered and allowed for, during a period, not of some few weeks or months, but through seventy-six long years; this is a task, about which are accumulated difficulties of no common order. It is a work of infinite complication, learning, ingenuity, and labour; nevertheless it was undertaken and accomplished in respect of the comet of 1835.

## LXXVIII.

### History of the Comet of 1835.

That comets were the causes, or at least the signs of famines and pestilences, and were followed by droughts and tempests, that they preceded civil commotions and great wars, and were especially fatal to princes, were things at one time believed, not only by the vulgar, but the learned. They were stated from chairs of theology and philosophy as facts established by the universal testimony of history. Of such historical records of the appearance of comets, and of the

prodigies which accompanied them, Pingré has collected some hundreds in his *Cometographie.* They have been exorcised as evil spirits.

The comet of 1835, when it came in 1456, was encountered by a papal bull, and the anathemas of the whole Catholic Church. Dismayed at once by the progress of the Turks and the progress of the comet, Calixtus included them both in the same prayer of conjuration ordered to be said in all the churches.

It came again in 1531, in 1607, and in 1682.

1759 was to be the next period of its appearance, and its coming was now, for the first time, *foreseen.* Halley, afterwards Savilian professor at Oxford, having undertaken to calculate the orbits of the different comets which had, up to that time, been observed, presented, in 1705, to the Royal Society, a work called *Cometographia,* in which he predicted* the return of the comet of 1682 in 1758, an announcement received in those days with no little surprise and interest. It was, however, immediately foreseen by astronomers, that the path of this comet would be disturbed by the attraction of the planet Jupiter. Lalande and Clairaut undertook to calculate the amount of this disturbance. The work was one of enormous labour, which they would never have undertaken, as Lalande himself admits, had not assistance been rendered to them (strange to say) by a lady. To Madame Lapaute, the wife of a celebrated watch-maker in Paris, was assigned a principal portion of their calculations, and to that lady is due a principal share in their success. "During six months we calculated from morning till night, even during meals," says Lalande. They determined the actual perturbations, during 150 years, of Jupiter and Saturn, and they arrived, finally, at the conclusion, that its coming would be delayed no less than 518 days by the attrac-

* His words, translated, are, "Hence I dare venture to foretel that it will return again in 1758."

tion of Jupiter, and 100 more days by Saturn. The time of its perihelion passage, or nearest approach to the sun, was thus brought to 13th April, 1759: it was, nevertheless, stated, that errors might have been made amounting to a month either way.

These conclusions Clairaut published to the world in November, 1758, when astronomers had already begun to look for the comet. It was first seen by a farmer of the name of Palitzch, near Dresden, on December 25, 1758, and at Paris, on January 21, 1759. It passed its perihelion on March 13, 1759, just one month after the time predicted.

The comet of 1759 was next to complete its orbit in 1835; and of its appearance in that year an account will now be given, the materials for which have been collected from the work, entitled, "Notice of Halley's Comet and its return in 1835," by M. de Pontécoulant.

## LXXIX.

### The Calculations of MM. Damoiseau and Pontécoulant.

The comet of 1835 was, in its last revolution, influenced appreciably by the attractions of the four planets, Jupiter, Saturn, Uranus, and the earth, and of course by the attraction of the sun; and MM. Damoiseau and Pontécoulant severally and independently undertook the task of calculating their amount, and separately completed it. M. Pontécoulant found that the action of Jupiter would, as compared with the last revolution of the comet, on the whole accelerate it 135·34 days; that of Saturn, retard it 51·53 days; that of Uranus, retard it 6·07 days; and that of the earth 11·7 days. The principal portion of the influence of the earth on its motions, dating as far back as the year 1759, or the very beginning of its revolution, at which time it passed very near the earth.

## LXXX.

### Predicted Time of the Appearance and Perihelion Passage of the Comet of 1835.

Allowance being made for these, the whole period of the comet's last revolution was brought to 27937 days, and counting from the 13th of March, 1759, when it last passed through its perihelion, or nearest extremity of its orbit to the sun, this brought its next perihelion passage to the 13th of November 1835.* At the same time M. Pontécoulant expressly stated that there might be an error of a few days in this time, and assigned as a proximate cause of such an error, a possible incorrectness in the assumed masses of some of the planets. His words are, "We must here once more repeat, that it is not pretended that the time announced for the comet's return to its perihelion may not be in error some days." Elsewhere he says, "Thus, then, it is *conclusive*, that *about the middle of November*, 1835, the passage of the comet through its perihelion will take place."

The determination of the time when the comet would first *appear*, was altogether another and a much less important matter. It depended upon the time when it would enter that portion of the heavens then visible at night, at that particular place—it depended upon the intensity of its light, as compared with what twilight there might be when it first appeared—it depended upon the state of the atmosphere. All these were variable elements, and none of them, except one, could be calculated upon with any certainty. It would have been madness to have mentioned a *particular day* when it should first be seen—nevertheless, both M. Pontécoulant and M. Damoiseau, ventured to announce it as probable, that it would appear during the first days of the month of August.

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* M. Damoiseau fixed its perihelion passage to the 4th of November.

## LXXXI.

### Actual Time of the Appearance and Perihelion Passage of the Comet of 1835.

The facts which astronomy reveals are so stupendous, her results so far beyond the range of ordinary thought, the steps which she takes through time and space so rapid, leaving even imagination far behind, that of all sciences, she would find least credit with the world, were it not for the predictions to which she appeals, and which everybody may verify. It is this prophetic power which constitutes her strength, her whole strength, or her weakness with the vulgar. Driven from every other test, there were people disposed to cavil at this science, (as there are always people disposed to cavil at what they do not understand,) who had fixed their criterion in the predicted return of the comet of 1759.

*Now what was the result?* It had been announced that the comet would probably be visible during the first days of August. *It was seen on the 5th of August at Rome,** *by MM. Dumouchel and Vico*, its light being then exceedingly feeble. But more than this, the *precise place* in the heavens which the comet would occupy on every day whilst it should be visible, had been calculated and announced beforehand, *and it was when they directed their telescope towards that point in the heavens which had been so predicted for the 5th of August, that MM. Dumouchel and Vico saw it.* It had been foretold that it would pass its perihelion on the 13th of November, that there might be an error of a few days, but that, nevertheless, it certainly would pass it about the middle of November. *It passed its perihelion on the 16th of November.*

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* The reader need not be reminded how pure and clear is the atmosphere of Rome.

It had been assigned by M. Pontécoulant, as a reason for the uncertainty which he thus felt in respect to the time of the perihelion passage, amounting, however, only to a few days, that the masses usually assigned to some of the planets by astronomers, and used by him in his calculations, might require correction. Of all the planets, Jupiter exercised the greatest influence over the motions of this comet. Any error in the mass which had been assigned to Jupiter, would, therefore, most affect the result. Now the mass he had assigned to Jupiter was such, that 1054 such masses would equal the mass of the sun. Recent observations have shown that the mass of Jupiter repeated only 1049 times would equal the mass of the sun; and it has been ascertained, that *if M. Pontécoulant had used in his calculation this corrected measurement of the mass of Jupiter, instead of that which he did use, it would have protracted the predicted time of the perihelion passage three days, and brought it to the 16th, and to within six hours of the time when it actually took place,—an error of six hours in a period of seventy-six years!*

The following are remarkable facts connected with the appearance of this comet, in 1835:*

It developed no tail until the 2nd of October, and on that day the nucleus was observed to become suddenly brighter, and to throw out a jet of light from its anterior part, or that *towards* the sun. Its tail attained its greatest length of 20° on the 15th October, and had entirely disappeared before its perihelion passage on the 16th November. "The anterior luminous jet, meanwhile, underwent," says Sir J. Herschel, "singular and capricious changes, succeeding one another with such rapidity that, on no two successive nights were the appearances alike." At one time it was single, at another "fan-shaped or swallow-tailed," while at other times "two, three, or even more jets, were darted from the comet in different directions." In receding from the sun it passed

* Herschel's "Outlines of Astronomy," p. 350.

through a series of changes scarcely less remarkable, and finally disappeared on the 5th of May.

## LXXXII.

### The Comet of 1843.

Of all the comets of modern times, one which suddenly appeared in 1843 was, as seen in southern latitudes, the most splendid and the most remarkable. Its head and nucleus were of extraordinary lustre, and its tail extended at first in a double, and afterwards in a single beam through 50 or 60 degrees of the heavens. It was seen in *broad daylight*, on the 28th of February, the day after its perihelion passage, and the distance of its nucleus from the sun was then measured with a sextant.* The smallness of this distance is the remarkable feature in the elements of its orbit. No other comet is recorded to have approached the sun so nearly. The space between it and the sun's luminous surface was not more than one-seventh of the sun's radius; whence it has been calculated that the solar heat to which it was subjected must have been 47,000 times that which we experience, and 24½ times as great as the heat which has been found sufficient to melt cornelian, agate, and rock crystal.

## LXXXIII.

### Biela's Comet in 1846.

On its return in 1846, the comet of Biela presented the remarkable phenomenon of a double comet. On the 13th of January it was seen thus double at Washington, the one comet being exceedingly small and faint in comparison with

* By Mr. Clarke, of Portland, United States. See Herschel's "Outlines," p. 368.

the other. From day to day it increased, however, in size and brightness, and appeared to separate from its companion, until, on the 16th of February, it had become the brighter of the two; it then gradually faded away, and disappeared on the 15th of March, and its companion on the 22nd of April. The tails of the two comets were parallel, and a remarkable streak of light, apparently thrown out by the new one, extended from it to the other. Their average distance from one another, from the 10th of February to the 22nd of March (according to M. Plantamour) was about two-thirds the distance of the moon from the earth's centre; and the increase of their separation during this time was not real, but only apparent.*

## LXXXIV.

### The Distances of the Stars.

In the commencement of this work, the nature of that change in the apparent positions of stationary objects which is produced by a change in the position from which we observe them has been explained. These changes are called parallactic. If we conceive two places of observation to be at equal distances from an object, the parallactic change produced by moving from the one place to the other is dependent, for its amount, upon this common distance, and on the distance of the places of observation from one another; so that, knowing any *two* of the three elements — first, the parallactic change in the angle of position; second, the distance of the places of observation from one another; third, the distance of either place of observation from the object,—we can find *the third.* Thus, knowing the two first, we can find the last, and it is thus that it has been attempted to determine the distances of the stars. As the earth moves round its orbit, the places whence we

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* Herschel's "Outlines," p 361.

observe them are continually changing, and thus a slight parallactic change is constantly taking place in the position of each star, which causes it to appear to describe a small elliptic orbit. The change which corresponds to two positions at opposite extremities of the same diameter of earth's orbit, is called the star's parallax. This change is, however, so small, that it is only by the aid of the most perfect instruments, and the most careful observations, that it can be detected, and that, only in respect to a very small number of stars. The first star whose parallax was satisfactorily ascertained was that known as 61 Cygni, which M. Bessel discovered, in the years 1847-8, to have a parallactic displacement, whose greatest amount was about $\frac{7}{20}$ths of a second. Within a few weeks of the publication of this discovery, Professor Henderson announced that of a parallax in the star α Centauri of about $\frac{10}{11}$ths of a second. The distances of these stars may readily be calculated from the consideration that they are to one another inversely as the corresponding parallaxes; and that, to a second of parallax, there corresponds (according to Sir J. Herschel), a distance of twenty billions of billions of miles. Thus, the distance of α Centauri is 22, and that of 61 Cygni 57 billions of billions of miles. The light of the former cannot be less than $3\frac{1}{4}$ years, or that of the latter, than $8\frac{1}{2}$ years, in reaching us.

The parallaxes of seven other stars appear since to have been satisfactorily determined, among which are that of α Lyræ, found by M. Struve to be about one quarter of a second, and that of Sirius, found to be somewhat less by Professor Henderson.

## LXXXV.

### Multiple Stars.

When first telescopes of any considerable power came to be made, it was discovered that certain stars which appeared

to the naked eye to be single, when seen through these telescopes, resolved themselves into two stars; these were called double stars. Stars of this kind have since been ascertained to be very numerous; and groups have been found not only of two, but of three and four stars. Of 120,000 stars examined by M. Struve, to ascertain whether they were multiple stars or not, 3057, or about one in forty, were found to be so.

Of the stars of which these systems are composed, one is frequently found greatly to exceed the rest in splendour.* It was imagined, at first, that this difference of brilliancy resulted from a great difference of distance; and did this difference of distance exist, it would offer a means of ascertaining the parallax, and, therefore, the actual distance of the whole group. Under this impression, Sir William Herschel undertook a series of observations at Slough, hoping to discover a parallactic motion in the stars; and, "as continually happens," says Arago,† "if people would but acknowledge it, in seeking for one thing he found another."

He discovered that, in many cases, double stars are not, as had hitherto been supposed, bodies isolated and independent of one another, placed by chance, so that lines drawn from them to the eye nearly coincided, but that they are systems, of which the greatest of the two is the central and controlling mass, round which the lesser star continually revolves, as do the planets of our system round the central sun. The lesser star will sometimes be seen to the east, at another in the west, or to the north or south of the greater star.

* One or both of the stars, composing a multiple system, sometimes shine not with white, but with coloured light; and their colours are, for the most part, different; every variety of colour is *found*, but the prevailing colours are blue, and green, and yellow.

† Notice sur les etoiles multiples annuaire, 1834.

## LXXXVI.

### The Laws of Gravitation extend to the Region of the Stars.

There are certain laws which govern the motions of the planets which compose our system, indicating, demonstratively, the nature of the force by which they are impelled towards their common centre. These laws, called Kepler's laws, have been stated in a previous part of this work. According to one of them, "the planets revolve round the sun, *not in circles but in ellipses*, and the sun does not occupy the *centre* of the elliptic orbit of each planet, but a point in it called its focus." Another of Kepler's laws may be enunciated as follows:—"An imaginary line being drawn from any planet of our system to the sun, although each such planet moves not in a circle but in an ellipse or oval, and not with the same constant velocity, but with a velocity continually varying; yet the space over which the line spoken of sweeps, in a given time, say a week, in any one portion of the planet's orbit, is the same as that over which it sweeps in any other:" this is called the law of the equal description of areas. The third of Kepler's laws is this:—"The larger axis of the ellipse being called its axis major, the periodic times of the different planets of our system are to one another in the ratio of the square roots of the cubes of these axes majores."

From the *second* of these laws it follows, that whatever is the force by which each planet is deflected from the rectilinear path it would otherwise travel in, the *direction* of that deflecting force is that of a straight line towards the sun. The *first* law shows this force to vary, as each planet in its path varies its distance from the sun, according to the proportion known to mathematicians as that of the *inverse square of the distance*. The *third* law shows the deflexions

of all the planets to result from the operation of *one and the same force* resident in the central sun operating upon all with an energy which varies from planet to planet, according to the same proportion that it varies for different distances of the *same* planet.

If then we find among these distant systems of stars, the same elliptic form of the orbit, and the same equal description of areas, we conclude that the stars of each system attract one another, and that the forces by which they are attracted vary inversely as the squares of the distances, and are, therefore, similar to gravity; and, lastly, that motion is there governed by the same laws as here. Now, we do find this to be the case. The motions of double stars have been very accurately observed, among others, by Sir John Herschel,* and he has ascertained that their motion is subject to these laws. In every respect do the relations which exist between the planetary motions obtain among the bodies which compose these far remote systems. What, then, is the

* The first determination of the elliptical orbit of a binary star ($\xi$ Ursæ) was made by M. Savary (*Connoiss. des Temps*, 1830.) In 1832, Sir John Herschel published an investigation of the orbits of several of the revolving stars, and the *Nautical Almanack* of 1835 contained ephemerides of two of them, deduced from these elements. The elements of the orbits of fourteen of them are given in Herschel's Outlines, whence the following are taken.—p. 573.

| Names of the Stars. | Periods of Revolution in Years. | Apparent Semi axis major of Ellipse of each. | Eccentricity. | By whom computed. |
|---|---|---|---|---|
| Herculis ......... | 31·468 | 1″ ·189 | 0·4445 | Mädler |
| $\eta$ Coronæ ...... | 43·246 | 1 ·088 | 0·3376 | Mädler |
| Ursæ Majoris | 58·262 | 3 ·857 | 0·4164 | Savary |
| $\alpha$ Centauri ...... | 77·000 | 15 ·500 | 0·9500 | Jacob |
| $\omega$ Leonis ......... | 82·533 | 0 ·857 | 0·6433 | Mädler |
| Bootis ......... | 117·140 | 12 ·560 | 0·5937 | Herschel, jun. |
| $\gamma$ Virginis ...... | 182·120 | 3 ·580 | 0·8795 | Herschel, jun. |
| Castor ............ | 252·660 | 8 ·086 | 0·7582 | Herschel, jun. |

conclusion, but that all these multiplied and isolated systems which people space, and of which the universe is the aggregate, are subject to the same conditions of motion and of force as obtain here? Thus the laws of gravitation and motion, which Newton showed to embrace at once the fall of bodies at the earth's surface, and the phenomena of our planetary system, must be extended to the region of the stars.

## LXXXVII.

### The Stars are not fixed.

If the stars—including amongst them the sun and solar system—gravitate to one another, they cannot but have a motion round their common centre of gravity. Observation appears to confirm this. The stars called fixed are not in reality so.

Thus the stars 61 Cygni, and $\epsilon$ Indi, have been ascertained to have apparent annual motions of $5''$ and $7''$ respectively; and Mr. Baily has published a list of 314 stars which are all believed to have annual motions of not less than $0''\cdot5$. This apparent motion is to be attributed partly to the motion of the stars, and partly to our own motion with the sun and system, of which we form a part. The point in the heavens towards which the motion of our system is taking place, has been fixed with considerable probability.* And the rate at which we are advancing towards that point, is stated by Sir J. Herschel, on a probable calculation, to be 154 millions of miles per annum, or about one-fourth the velocity of the earth in its orbit.

## LXXXVIII.

### Variable and Temporary Stars.

Among the most remarkable phenomena of the heavens are the variations in the brightness of certain stars, and the

* In R. A. 259° 9′, and N. P. D. 55° 23′. See Herschel's "Astronomy," p. 583.

disappearance of others. Of the class of variable stars some vary periodically, attaining by degrees a maximum lustre, then passing to a minimum, and increasing again, or fading out and reappearing. The stars Algol and Omicron Ceti are of this class. The former appears as a star of the second magnitude for about $2\frac{1}{2}$ days, then passes in $3\frac{1}{2}$ hours to a star of the fourth magnitude, and after a quarter of an hour begins again to increase, and regains its former magnitude in another period of $3\frac{1}{2}$ hours. The latter disappears twelve times in every eleven years, and remains after each disappearance invisible for five months. Many other stars appear thus to vary in brightness periodically, but there are also some whose variations appear to be subject to no law. Of this class is one which appeared suddenly in 1572, and increased until it exceeded Jupiter in brightness, being seen at mid-day. It disappeared in 1574. Another of the same class is the southern star, $\eta$ Argûs, which has been observed, since the year 1677, to vary uncertainly between the fourth and first magnitudes, sometimes increasing and sometimes diminishing, until, in 1843, it nearly equalled Sirius in splendour.*

## LXXXIX.

### The Galaxy.

The Galaxy, or Milky-way, passes through the heavens like an irregular zone, imperfectly luminous, and inclined at about 60° to the ecliptic, which it cuts near the solstitial points. It was discovered by Sir William Herschel to be an accumulation of minute stars. He conceived, however, the idea that this apparent accumulation was not due to the stars being placed more nearly together there than in any other region of space, but, to a greater depth behind one another. If our system be conceived to be situated, not in the centre of a space through which the stars are distributed

* Herschel's "Outlines," p. 561.

equally in all directions, but, of a lamina or stratum of stars which intersects the heavens in the milky way, and whose dimension measured parallel to its flat side are great, but small in the direction perpendicular to it, or parallel to its edge, it is evident that many stars lying behind one another in the one direction, and but few in the other, they will appear in the one, thickly, and in the other, thinly strewed over the heavens. By this hypothesis the apparent accumulation of stars in the milky way is accounted for. If the lamina be conceived to be split parallel to its flat side and slightly separated through different portions of its substance, the bifurcations of the milky way will be explained. The stars being assumed to be distributed at equal distances from one another through the substance of this lamina, it is evident that the number of stars which appear on a given area (the field of view of a telescope, for instance,) when we look through it in any direction, will be proportional to the depth of visible stars in that direction, and may be taken as a gauge of it. It was thus that he sounded the heavens, as with a line, by comparing the richness in stars of different regions of them. These observations have since been repeated and found to follow nearly the same laws in the southern as in the northern hemisphere; " the mean density of the stars in the galactic circle exceeding that in its poles, in the ratio of nearly 30 to 1.*

* Herschel's " Outlines," p. 533.

THE END.

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